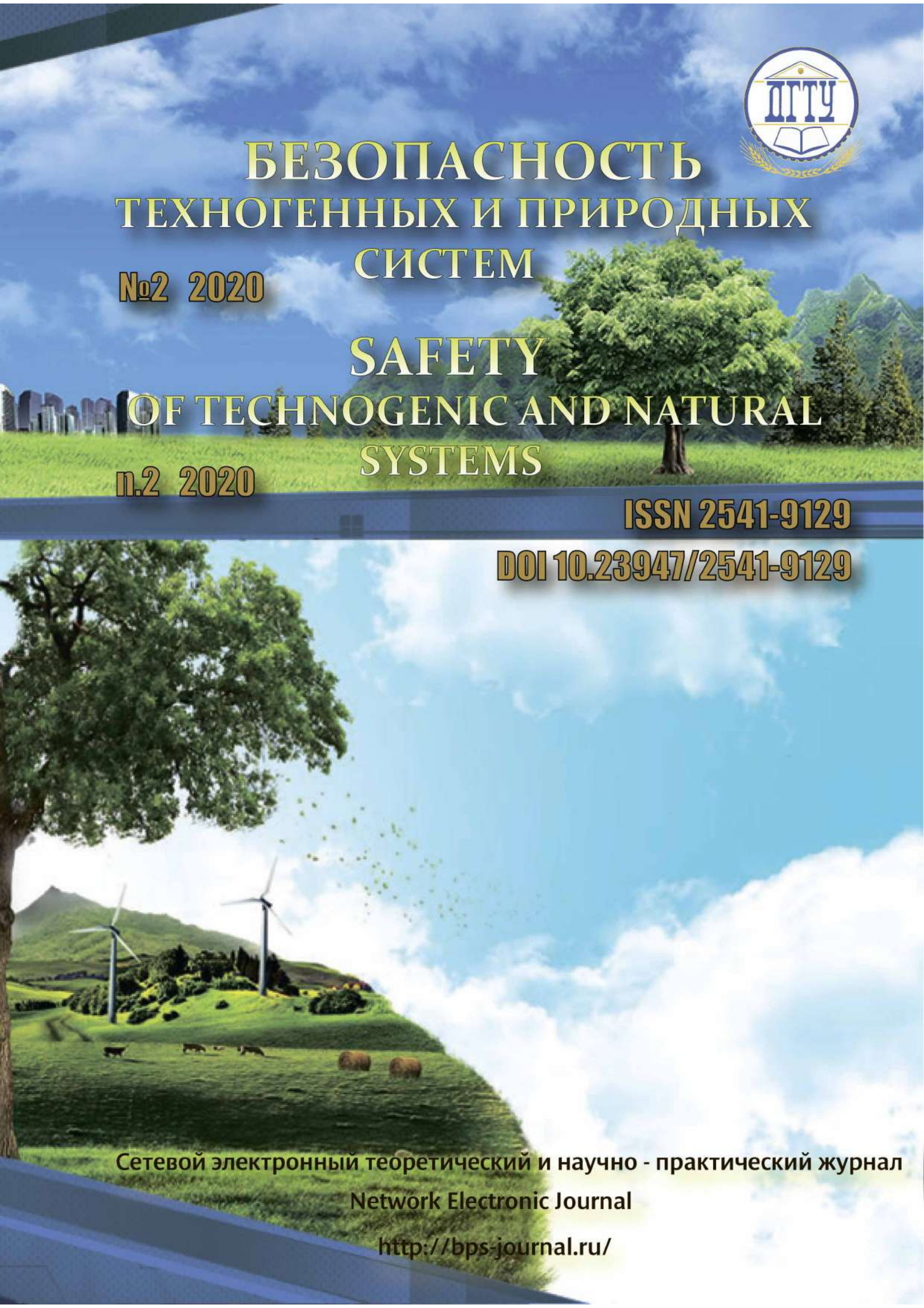

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Application of emergency process development modeling and risk assessment to ensure safe operation of oil and gas industrial facilities

K. N. Abdrakhmanova, V. V. Shabanova, A. V. Fedosov, N. Kh. Abdrakhmanov

Ufa State Petroleum Technological University (Ufa, Russian Federation)

Introduction. One of the main tasks of the production organization is to prevent accidents. In the oil and gas industry, a significant part of accidents occur on process pipelines. Depressurization of the process pipeline leads to negative consequences up to a complete shutdown of production and can cause human casualties. Modeling the pipeline depressurization process in accordance with accident scenarios is one of the approaches to ensuring the safety of technological pipelines.

Problem Statement. The purpose of this study is to model the process of pipeline depressurization in accordance with scenarios of industrial accidents under certain environmental conditions.

Theoretical Part. In most cases, the main causes of accidents are internal hazards associated with depressurization and destruction of technical devices, as well as personnel errors due to violation of the requirements of the organization and production of hazardous work. There is no unified methodology for drawing up a scenario for the development of accidents at hazardous production facilities, and the existing guidelines for determining possible scenarios are of a recommendatory nature. Various types of fire and explosive process media located inside the pipeline are considered in the preparation of scenarios. The object of experiments was a 3D model of an industrial site with a hypothetical process pipeline under such variables as building density, meteorological conditions, and air mass stagnation zones. The latter were modeled in the FlowVision software package, which visualizes three-dimensional liquid and gas flows.

Conclusion. The developed universal algorithm made it possible to create scenarios for the development of an emergency situation on a hypothetical process pipeline. The results are applicable for further modeling of emergency situations.

Keywords*:* accident, modeling, risk, process pipeline, depressurization, oil and gas industry, production, safe operation.

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Introduction. Accidents in oil and gas industry are usually characterized by significant emissions of dangerous substances that negatively affect natural and social environment, cause serious economic damage, and are dangerous to human health and life.

In most cases, such incidents provoke internal hazards. The main ones are listed below:

— depressurization and destruction of technical devices,

— staff errors,

— violation of the requirements for organizing and performing dangerous types of work [1-3].

It is impossible to completely exclude accidents at hazardous production facilities. That is why the problems of preventing accidents in oil and gas industry, as well as eliminating the severe consequences of such events, remain relevant [4]. In addition, it is of interest to prevent accidents at the stage of defect formation.

Accidents on process pipelines. In oil and gas industry, most accidents occur on process pipelines. The analysis of causes and consequences of accidents on domestic technological pipelines revealed main sources of risks: unsatisfactory condition of the equipment, corrosion, thinning of the wall thickness, violation of industrial safety requirements and the human factor. Some enterprises have been operating for many decades and are equipped with outdated equipment with serious defects.

Depressurization of process pipelines leads to negative consequences up to a complete shutdown of production and can cause human casualties.

Problem Statement. One of the ways to ensure safety of technological pipelines is to model the depressurization process in accordance with accident scenarios. This approach allows us to determine the most vulnerable, critical from the point of view of safety pipeline parts [3, 5]. The purpose of this study is to model the process of pipeline depressurization in accordance with scenarios of industrial accidents under certain environmental conditions.

Theoretical Part

Emergency situations modeling. As part of risk analysis at a hazardous production facility (HPF), the scenarios for the development of an emergency situation can be determined (Fig. 1).

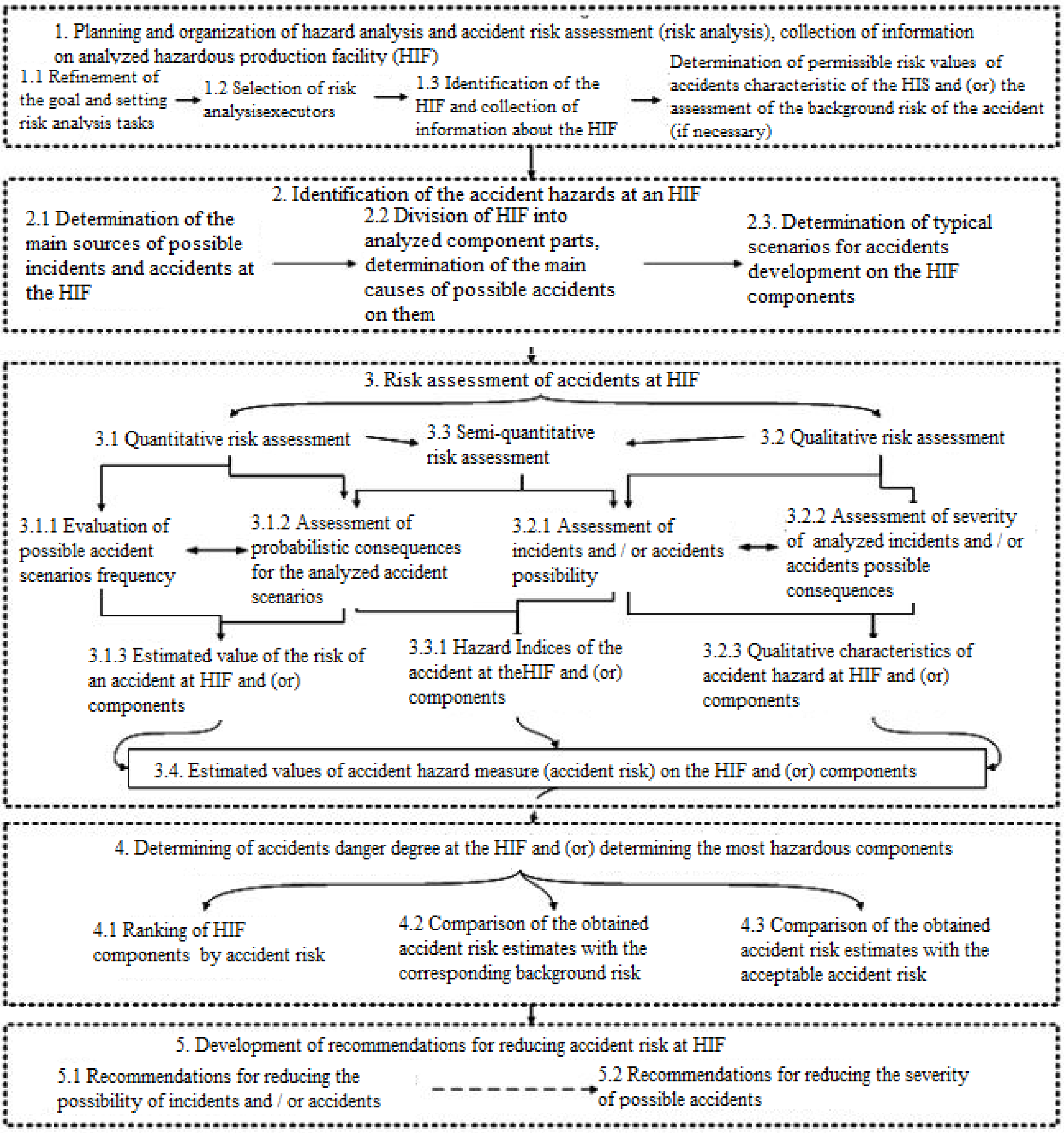

1. Planning and organization of hazard analysis and accident risk assessment (risk analysis), collection of information on analyzed hazardous production facility (HIF)
1.1 Refinement of the goal and setting risk analysis tasks
1.2 Selection of risk analysisexecutors
1.3 Identification of the HIF and collection of information about the HIF
Determination of permissible risk values of accidents characteristic of the HIS and (or) the assessment of the background risk of the accident (if necessary)
2. Identification of the accident hazards at an HIF
2.1 Determination of the main sources of possible incidents and accidents at the HIF
2.2 Division of HIF into analyzed component parts, determination of the main causes of possible accidents on them
2.3. Determination of typical scenarios for accidents development on the HIF components
3. Risk assessment of accidents at HIF
3.1 Quantitative risk assessment
3.3 Semi-quantitative risk assessment
3.2 Qualitative risk assessment
3.1.1 Evaluation of possible accident scenarios frequency
3.1.2 Assessment of probabilistic consequences for the analyzed accident scenarios
3.2.1 Assessment of incidents and / or accidents possibility
3.2.2 Assessment of severity of analyzed incidents and / or accidents possible consequences
3.1.3 Estimated value of the risk of an accident at HIF and (or) components
3.3.1 Hazard Indices of the accident at theHIF and (or) components
3.2.3 Qualitative characteristics of accident hazard at HIF and (or) components
3.4. Estimated values of accident hazard measure (accident risk) on the HIF and (or) components
4. Determining of accidents danger degree at the HIF and (or) determining the most hazardous components
4.1 Ranking of HIF components by accident risk
4.2 Comparison of the obtained accident risk estimates with the corresponding background risk
4.3 Comparison of the obtained accident risk estimates with the acceptable accident risk
5. Development of recommendations for reducing accident risk at HIF
5.1 Recommendations for reducing the possibility of incidents and / or accidents
5.2 Recommendations for reducing the severity of possible accidents

Fig. 1. General scheme of hazard analysis and risk assessment of accidents at HPF

There is no unified methodology for creating a scenario for the development of accidents at hazardous production facilities, and the existing guidelines are of a recommendatory nature. The developed algorithm for creating scenarios for the development of an emergency situation, shown in Fig. 2, can be used for risk assessment at the HPF [6, 7].

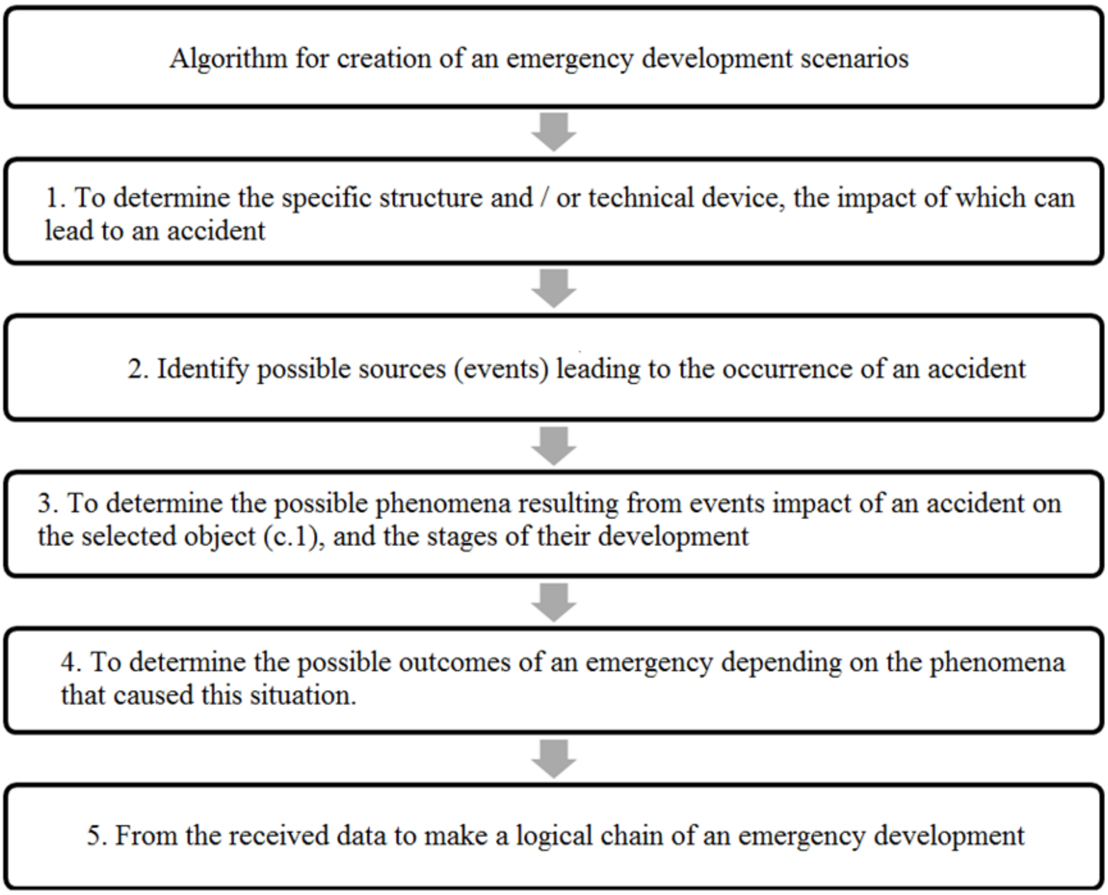

Algorithm for creation of an emergency development scenarios
1. To determine the specific structure and / or technical device, the impact of which can lead to an accident
2. Identify possible sources (events) leading to the occurrence of an accident
3. To determine the possible phenomena resulting from events impact of an accident on the selected object (c.1), and the stages of their development
4. To determine the possible outcomes of an emergency depending on the phenomena that caused this situation.
5. From the received data to make a logical chain of an emergency development

Fig. 2. Algorithm for creating emergency scenarios

The developed algorithm was used in the preparation of scenarios for the development of an emergency situation on a hypothetical process pipeline (it is considered as an object, the impact on which can lead to an accident). When preparing scenarios (Fig. 3, 4), various types of technological fire and explosive environments located inside the pipeline are considered. It was determined that the presence of any group of technological environment in the pipeline generally does not affect the change in the chain of events occurring during an accident [8, 9].

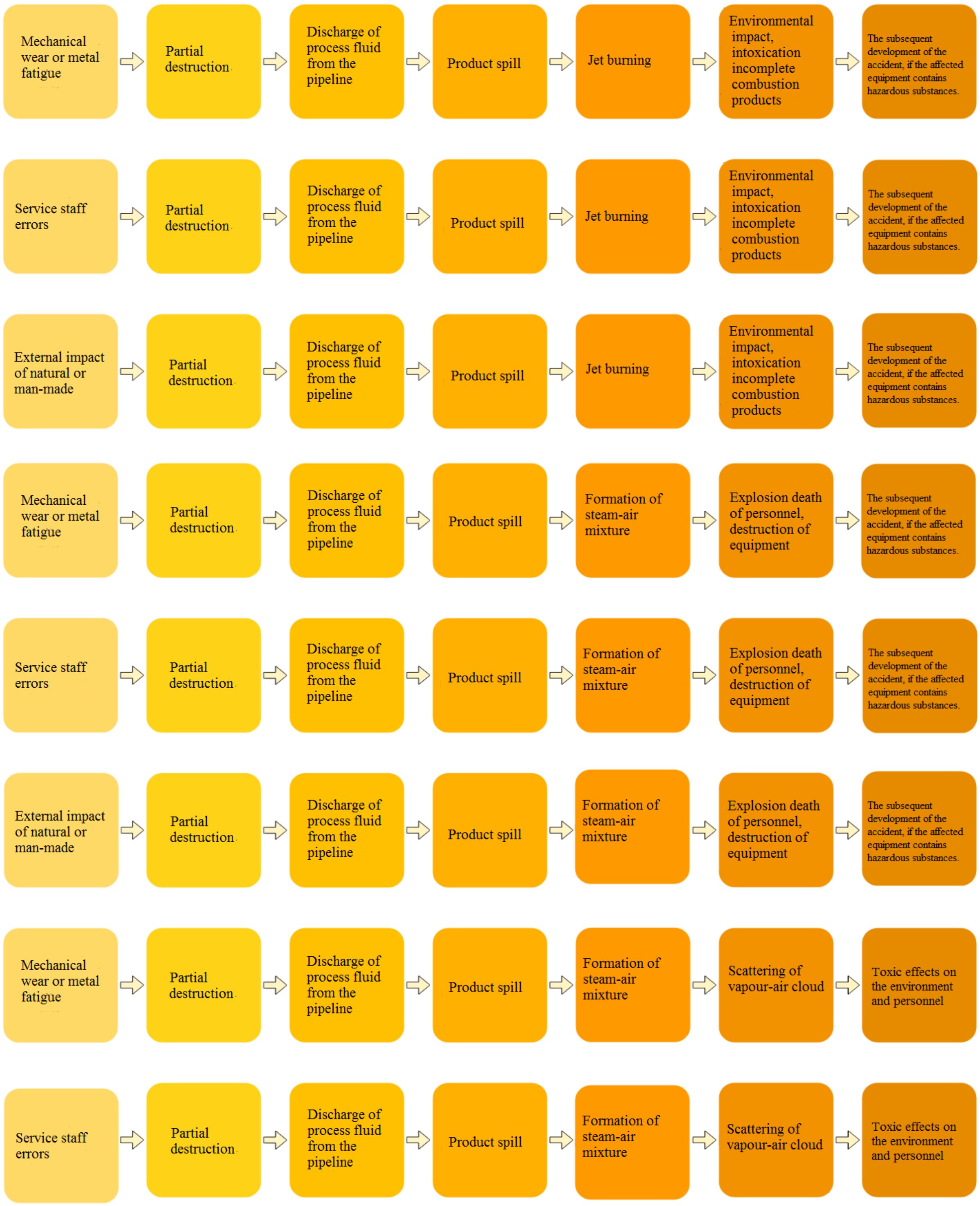

Mechanical wear or metal fatigue
Partial destruction
Discharge of process fluid from the pipeline
Product spill
Jet burning
Environmental impact, intoxication incomplete combustion products
The subsequent development of the accident, if the affected equipment contains hazardous substances.
Service staff errors
Partial destruction
Discharge of process fluid from the pipeline
Product spill
Jet burning
Environmental impact, intoxication incomplete combustion products
The subsequent development of the accident, if the affected equipment contains hazardous substances.
External impact of natural or man-made
Partial destruction
Discharge of process fluid from the pipeline
Product spill
Jet burning
Environmental impact, intoxication incomplete combustion products
The subsequent development of the accident, if the affected equipment contains hazardous substances.
Mechanical wear or metal fatigue
Partial destruction
Discharge of process fluid from the pipeline
Product spill
Formation of steam-air mixture
Explosion death of personnel, destruction of equipment
The subsequent development of the accident, if the affected equipment contains hazardous substances.
Service staff errors
Partial destruction
Discharge of process fluid from the pipeline
Product spill
Formation of steam-air mixture
Explosion death of personnel, destruction of equipment
The subsequent development of the accident, if the affected equipment contains hazardous substances.
External impact of natural or man-made
Partial destruction
Discharge of process fluid from the pipeline
Product spill
Formation of steam-air mixture
Explosion death of personnel, destruction of equipment
The subsequent development of the accident, if the affected equipment contains hazardous substances.
Mechanical wear or metal fatigue
Partial destruction
Discharge of process fluid from the pipeline
Product spill
Formation of steam-air mixture
Scattering of vapour-air cloud
Toxic effects on the environment and personnel
Service staff errors
Partial destruction
Discharge of process fluid from the pipeline
Product spill
Formation of steam-air mixture
Scattering of vapour-air cloud
Toxic effects on the environment and personnel

Fig. 3. Scenarios for the development of an emergency situation with the complete destruction of the process pipeline

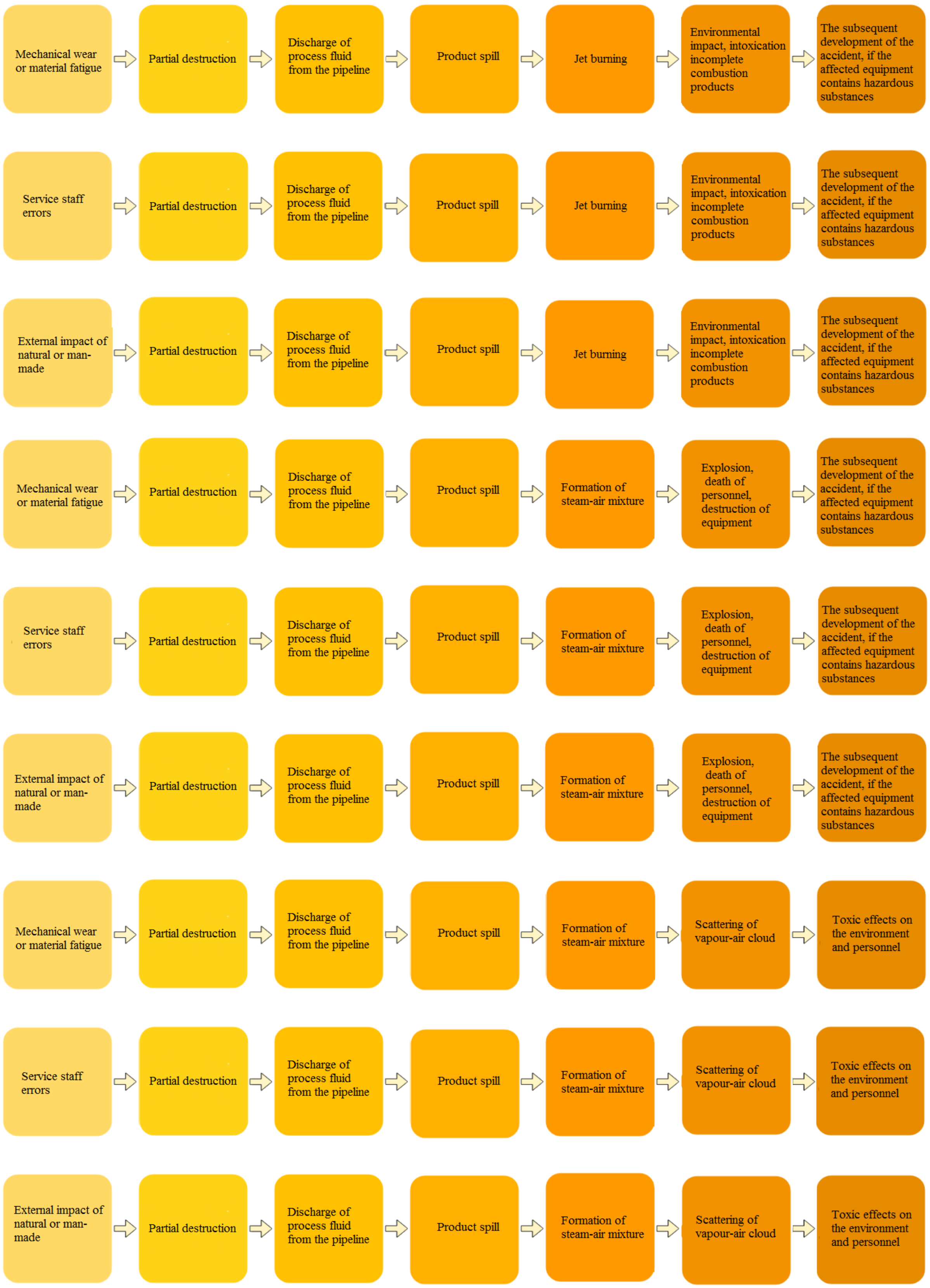

Mechanical wear or material fatigue
Partial destruction
Discharge of process fluid from the pipeline
Product spill
Jet burning
Environmental impact, intoxication incomplete combustion products
The subsequent development of the accident, if the affected equipment contains hazardous substances
Service staff errors
Partial destruction
Discharge of process fluid from the pipeline
Product spill
Jet burning
Environmental impact, intoxication incomplete combustion products
The subsequent development of the accident, if the affected equipment contains hazardous substances
External impact of natural or man-made
Partial destruction
Discharge of process fluid from the pipeline
Product spill
Jet burning
Environmental impact, intoxication incomplete combustion products
The subsequent development of the accident, if the affected equipment contains hazardous substances
Mechanical wear or material fatigue
Partial destruction
Discharge of process fluid from the pipeline
Product spill
Formation of steam-air mixture
Explosion, death of personnel, destruction of equipment
The subsequent development of the accident, if the affected equipment contains hazardous substances
Service staff errors
Partial destruction
Discharge of process fluid from the pipeline
Product spill
Formation of steam-air mixture
Explosion, death of personnel, destruction of equipment
The subsequent development of the accident, if the affected equipment contains hazardous substances
External impact of natural or man-made
Partial destruction
Discharge of process fluid from the pipeline
Product spill
Formation of steam-air mixture
Explosion, death of personnel, destruction of equipment
The subsequent development of the accident, if the affected equipment contains hazardous substances
Mechanical wear or material fatigue
Partial destruction
Discharge of process fluid from the pipeline
Product spill
Formation of steam-air mixture
Scattering of vapour-air cloud
Toxic effects on the environment and personnel
Service staff errors
Partial destruction
Discharge of process fluid from the pipeline
Product spill
Formation of steam-air mixture
Scattering of vapour-air cloud
Toxic effects on the environment and personnel
External impact of natural or man-made
Partial destruction
Discharge of process fluid from the pipeline
Product spill
Formation of steam-air mixture
Scattering of vapour-air cloud
Toxic effects on the environment and personnel

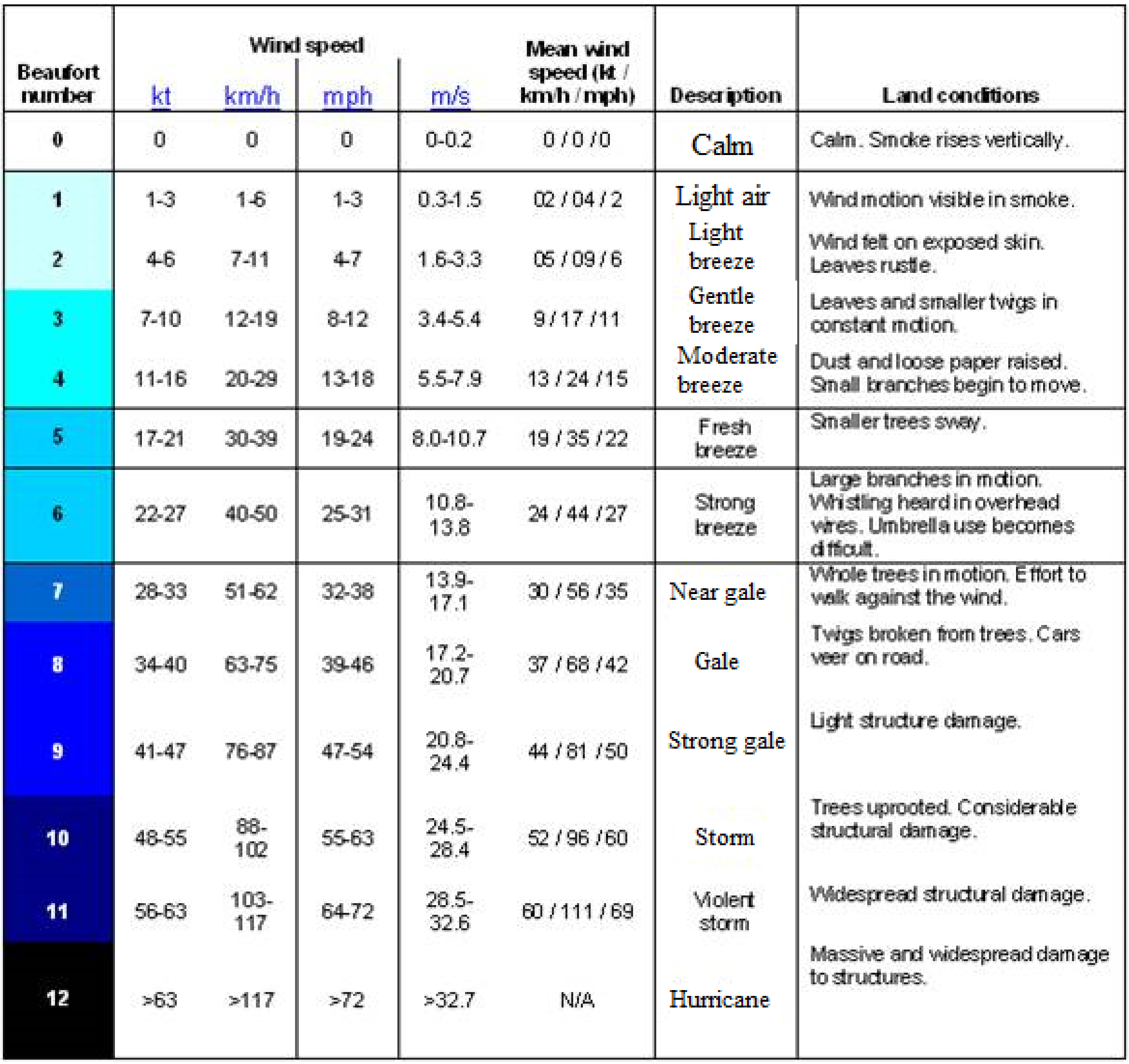
Fig. 4. Scenarios for the development of an emergency situation in case of partial destruction of the process pipeline

According to Fig. 3-4, depressurization of the process pipeline is the cause of product spillage. Vapor-gas-air mixture, in turn, is formed because of the spillage. Modeling the stress state based on the actual state of the pipeline can provide more detailed information about a possible spill.

The resulting cloud will drift along the earth surface until the source of ignition is found. This will create areas of gas accumulation and stagnation zones, the size of which mainly depends on the environmental conditions, terrain and building density. In order to prevent accidents, it is necessary to develop and implement emergency situations development models in production practice, taking into account building density and meteorological conditions at a particular object [10, 11].

Meteorological characteristics as one of the main factors of hydrocarbons combustion determine the extent of the damage. The number of options for spreading explosive substances in the atmosphere significantly increases if we take into account meteorological conditions, possible wind directions and speeds.

The World Meteorological Organization has adopted the Beaufort scale (Fig. 5) to approximate wind speed based on its impact on ground objects.



Beaufort number	Wind speed kt	km/h	mph	m/s	Mean wind speed (kt / km/h / mph)	Description	Land conditions
0	0	0	0	0-0.2	0 / 0 /0	Calm	Calm. Smoke rises vertically.
1	1-3	1-6	1-3	0.3-1.5	02 / 04 / 2	Light air	Wind motion visible in smoke.
2	4-6	7-11	4-7	1.6-3.3	05 / 09 / 6	Light breeze	Wind felt on exposed skin. Leaves rustle.
3	7-10	12-19	8-12	3.4-5.4	9 / 17 /11	Gentle breeze	Leaves and smaller twigs in constant motion.
4	11-16	20-29	13-18	5.5-7.9	13 / 24 /15	Moderate breeze	Dust and loose paper raised. Small branches begin to move.
5	17-21	30-39	19-24	8.0-10.7	19 / 35 /22	Fresh breeze	Smaller trees sway.
6	22-27	40-50	25-31	10.8-13.8	24 / 44 /27	Strong breeze	Large branches in motion. Whistling heard in overhead wires. Umbrella use becomes difficult.
7	28-33	51-62	32-38	13.9-17.1	30 / 56 /35	Near gale	Whole trees in motion. Effort to walk against the wind.
8	34-40	63-75	39-46	17.2-20.7	37 / 68 /42	Gale	Twigs broken from trees. Cars veer on road.
9	41-47	76-87	47-54	20.8-24.4	44 / 81 /50	Strong gale	Light structure damage.
10	48-55	88-102	55-63	24.5-28.4	52 / 96 /60	Storm	Trees uprooted. Considerable structural damage.
11	56-63	103-117	64-72	28.5-32.6	60 / 111 / 69	Violent storm	Widespread structural damage.
12	>63	>117	>72	>32.7	N/A	Hurricane	Massive and widespread damage to structures.

Fig. 5. Beaufort Scale

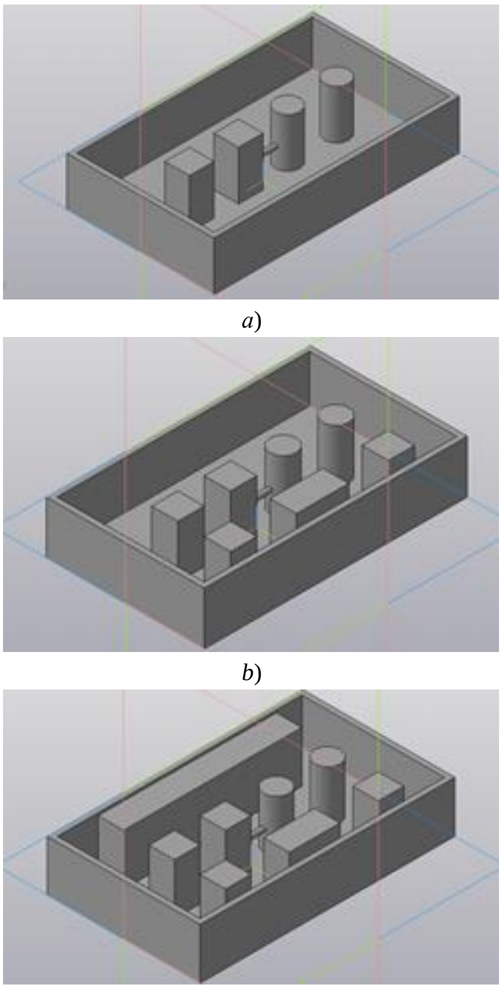
Building density is one of the most important factors for assessing risk and predicting emergencies at hazardous production facilities.

Building density is the ratio of the building area to the area of the enterprise within the fence. In other words, building density refers to the intensity of use of the territory. As a rule, the minimum building density for oil and gas facilities is about 45 %.

It is obvious that building density significantly affects the development of an emergency. That is why it is recommended to take into account both meteorological conditions and building density when forecasting and assessing risks. This work also identifies the worst-case wind direction. A 3D model of an industrial site was created, and then the air flow directions were modeled on it [12, 13].

The model of the site of the industrial facility was built in the three-dimensional design system "Compass-3D". To do this, the following items are created sequentially: a detail; a parallelepiped; sketches of buildings, structures, and equipment.

Within the framework of the study, three conditional models of a section with a hypothetical process pipeline that connects two objects were created (Fig. 6).



a)

b)

c)

Fig. 6. Models of an industrial site with a hypothetical process pipeline: minimum building density (a), medium building density (b), high building density (c)

On a site with a minimum building density, the external environment has the maximum impact on the pipeline in adverse weather conditions. Under the same conditions and medium building density, the pipeline is partially exposed to the external environment. Accordingly, high building density provides minimal impact on the object.

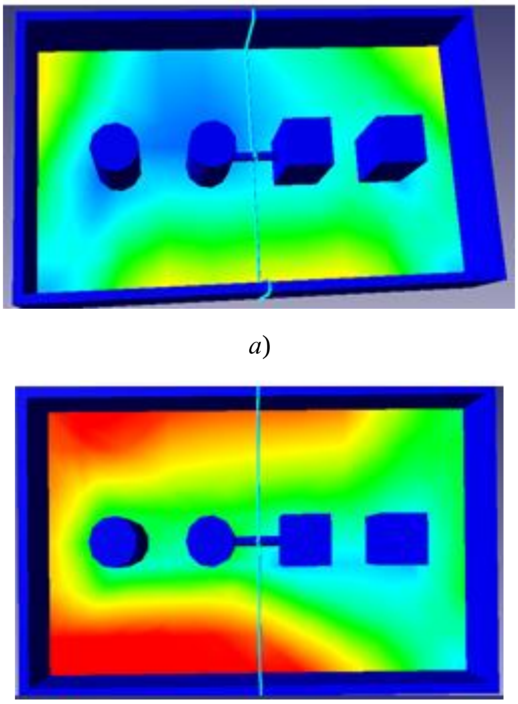
At the final stage of the simulation, we work on the zones of air mass stagnation. For this purpose, the FlowVision software package is used, which visualizes three-dimensional flows of liquid and gas in technical and natural objects [14].

An incompressible liquid is set as a mathematical model. The selected substance is air.

To create air flow models, we used 3D models of industrial sites with different building densities — minimum, medium and high.

The specified wind speed corresponds to 3 points on the Beaufort scale (5 m/s). According to the set parameters "input", "output" and "wall", air masses will enter and exit the model with a certain building density. The paper considers models of the direction of air flows from all directions of the world, so the boundary conditions change depending on the wind direction.

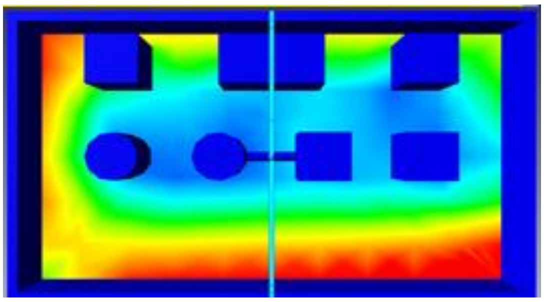
In all FlowVision models, air stagnation zones differ in a spectrum of cold colors: from dark blue to light blue (Fig. 7-9) [15].



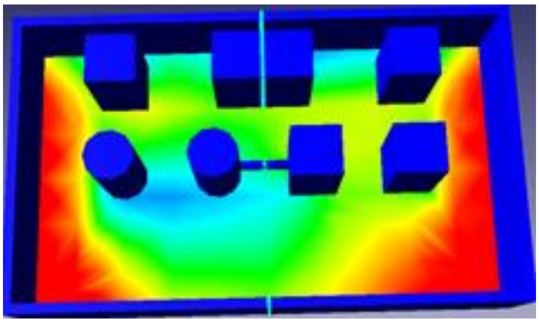
a)

b)

Fig. 7. Model of air flow direction at the site of the industrial facility with the minimum building density with the largest (a) and smallest (b) number of air masses stagnation zones

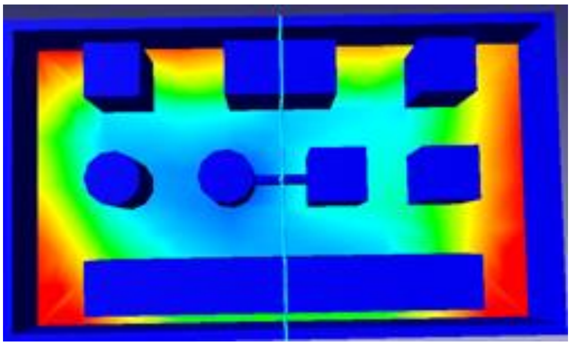


a)

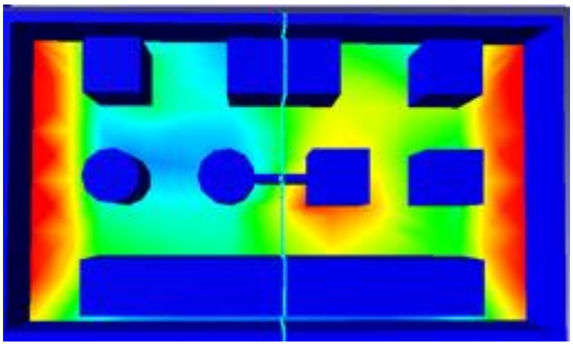


b)

Fig. 8. Model of air flow direction at the site of the industrial facility with the medium building density with the largest (a) and smallest (b) number of air masses stagnation zones



a)



b)

Fig. 9. Model of air flow direction at the site of the industrial facility with the maximum building density with the largest (a) and smallest (b) number of air masses stagnation zones

In this paper, 24 models of the industrial site with different wind directions depending on the cardinal directions are obtained. From them:

— 8 with a minimum building density,

— 8 with a medium building density,

— 8 with the maximum building density.

There were more than 50 experiments.

When evaluating the results, it was assumed that the object was exposed to the greatest damage with the maximum number of air masses stagnation zones (models with the same building density are compared). With a minimum number of stagnation zones the scale of an accident will increase, affecting a large territory.

Comparing the models designed in FlowVision, you can make the following statements.

The process pipeline and its surrounding area are least affected if the spill fire occurred on a site with minimal building density with air flows from South to North. If the air flows from North to West, the scale of the accident will increase, affecting a large area.

If the average building density is considered, then the largest number of air mass stagnation zones will be in the model with the wind direction from West to East. The model with the North-South direction of air flows has the smallest number of stagnation zones, which corresponds to a larger area of destruction as a result of the spill fire.

At the maximum building density, the model with the wind direction from East to West has the largest number of air mass stagnation zones, and the model with the wind direction from South to North has the smallest number.

Conclusion. The results of the experiments allow us to draw the following conclusions. The number of air mass stagnation zones in all models depends primarily on the wind direction. At the same time, the existence of a clear dependence of the number of air masses stagnation zones on a specific wind direction is not established. This means that when placing equipment, including process pipelines, buildings, etc. at industrial enterprises, you should take into account the most likely wind directions during certain periods of the year (summer, winter). In addition, it confirms the need to draw up a wind diagram for a specific region, the area where the industrial facility will be located.

When modeling the development of an accident during the depressurization of a process pipeline, it is important to take into account not only the meteorological conditions that correspond to this region, but also the building density of the enterprise.

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Information about the authors:

Abdrakhmanova, Karina N., Post-graduate student, Department of Fire and Industrial Safety, Ufa State Petroleum Technological University (1, Kosmonavtov street, Ufa, 450062, RF) ORCID: https://orcid.org/0000–0002–5238–6473, akarinan@mail.ru

Shabanova, Vilena V., Student, Department of Industrial Safety and Labor Protection, Ufa State Petroleum Technological University (1, Kosmonavtov street, Ufa, 450062, RF), ORCID: https://orcid.org/0000–0001–7838–7186, rener06@rambler.ru

Fedosov, Artem V., Associate Professor, Department of Industrial Safety and Labor Protection, Ufa State Petroleum Technological University (1, Kosmonavtov street, Ufa, 450062, RF), Cand. Sci., ORCID: https://orcid.org/0000–0002–7853–1800, fedsv-artem@rambler.ru

Abdrakhmanov, Nail Kh., Head, Department of Industrial Safety and Labor Protection, Ufa State Petroleum Technological University (1, Kosmonavtov street, Ufa, 450062, RF), Dr. Sci., Professor, ORCID: https://orcid.org/0000–0002–3184–1975, anailx@mail.ru

Contribution of the authors:

K. N. Abdrakhmanova and V. V. Shabanova — experimental research and patent analysis. A. V. Fedosov — literary, patent analysis and participation in theoretical research. N. Kh. Abdrakhmanov — formulation of the main idea of research and article structure, editing.

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Certification system for specialists of transport enterprises

E. V. Egelskaya, D. N. Sorokina

Don State Technical University (Rostov-on-Don, Russian Federation)

Introduction. Transport companies join together employees of various specialties, but one of the main ones is a specialist responsible for road safety and a specialist in technical diagnostics and control over the technical condition of vehicles. The level of competence, qualifications, and experience of these specialists determines not only the accident-free operation of the transport company, but also the provision of safe working conditions for the staff.

Problem Statement. As a result of studying the requirements for these specialists, it was established that in order to maintain the level of knowledge and professional competence, these specialists must undergo regular certification. This article is devoted to the content of the system of certification of specialists.

Theoretical Part. Currently, control over the level of professional competence of specialists can be organized both inside the enterprise, in accordance with the administrative documents of the head of the enterprise, in the Commission of Rostransnadzor, and in specially created centers for evaluating qualifications. For a person responsible for road safety, the procedure for monitoring his knowledge and skills is established, and a specialist in technical diagnostics and control over the technical condition of vehicles works on the basis of professional standards

Conclusion. Regulations on the formation of a certification system for specialists of transport enterprises are aimed at improving road safety. Currently, the procedure for determining whether a specialist's knowledge meets the required competencies of the professional standard is not regulated, so the employer evaluates the specialist's qualifications independently, taking into account regulatory requirements.

Keywords: transport enterprise, certification of specialists, professional standard, technical diagnostics, control, technical condition, vehicle.

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Introduction. Transport is one of the most important components of Russia's industrial infrastructure. Its effective and stable functioning is the key to improving the quality of life of the population. The main task of transport is to meet the needs of the population in timely and complete transportation and delivery of goods. There are a large number of transport companies that are directly engaged in the transportation of passengers and cargo, as well as enterprises that have vehicles.

According to statistics, vehicles of transport companies become participants in road accidents much more often than private vehicles [1, 2]. Currently, the most dangerous is bus transport. It should be taken into account that buses have a much greater risk of causing damage to other traffic participants compared to passenger cars.

Main causes of road accidents are violations of traffic rules by drivers and technical failures of vehicles. There are many factors that can cause an accident. There is a comprehensive approach to solving this problem, but the number of accidents still remains at a high level [3, 4]. It is established that the human factor is the cause of most accidents — the lack of appropriate skills of employees, low level of responsibility, psycho-emotional overload, etc.

Problem Statement. The purpose of this study is to develop the main provisions of the formation of certification system of transport companies' specialists that ensure road safety. The developed system is based on the regulatory documents in this industry, as well as on the regional characteristics of the enterprise and vehicles. To solve this task, it is necessary to justify the requirements for specialists of transport enterprises. When forming the requirements, it should be emphasized that the causes of accidents can be:

- lack of appropriate monitoring of the technical condition of vehicles;
- use of faulty equipment;
- incorrect logistics decisions;
- insufficient organization of road safety, that is, failure to perform direct functions by specialists responsible for safety, as well as specialists in technical diagnostics and monitoring of the technical condition of vehicles.

Theoretical Part. A comprehensive system for ensuring the necessary level of professional competence should contain two main sections:

- justification and formation of the requirements for specialists;
- creation of a permanent certification system for transport enterprises’ employees.

Let us consider the requirements for specialists of transport companies. To reduce the severity of road accidents consequences, modern requirements for the professional competence of transport workers, requirements for knowledge, skills and abilities in accordance with the working conditions of personnel and labor functions are formed, which is the basis for certification and assessment of qualifications. A sufficient level of professional training, confirmed by certification, is a guarantee of safe transportation by road.

There are a number of legislative documents that define the requirements for road safety, passenger and cargo transportation. One of the fundamental normative documents is Federal law of 10.12.1995 no. 196-FZ "On road traffic safety" [5], according to which legal entities and individual entrepreneurs engaged in transportation by road and urban land electric transport are required to:

- ensure that the organization has an official responsible officer for road safety who has passed the certification;
- ensure that employees meet the professional and qualification requirements for transportation;
- ensure the availability of premises and equipment necessary for parking, maintenance and repair of vehicles, or the conclusion of appropriate contracts with specialized organizations;
- organize and conduct pre-trip monitoring of the technical condition of vehicles.

To meet these requirements, transport companies must appoint a specialist responsible for road safety and a specialist for diagnosing and monitoring the technical condition of vehicles.

Certification of specialists of transport enterprises should be implemented in accordance with the following approaches:

- officer responsible for road safety should be qualified according to Order of the Ministry of Transport of Russia of 28.09.2015 no. 287 "On approval of professional and qualification requirements for employees of legal entities and individual entrepreneurs engaged in road transport and urban ground electric transport" [6];
- specialist in technical diagnostics and control over the technical condition of vehicles must meet the requirements of the professional standard "Specialist in technical diagnostics and control over the technical condition of vehicles during periodic technical inspection" [7].

Let us consider the certification system for transport enterprises’ specialists. Order no. 287 of the Ministry of Transport of the Russian Federation dated 28.09.2015 defines the requirements for certification of those responsible for road safety. Certification can be carried out by the territorial bodies of the Federal Service for Supervision of Transport and the Federal Budget Institution "Agency for Road Transport". For specialists in technical diagnostics and control over the technical condition of vehicles engaged in work in accordance with the professional standard, the procedure for establishing compliance with the required competencies is not normalized at present.

In accordance with article 195.1 of the Labor Code of the Russian Federation, a professional standard is a characteristic of the qualification required for an employee to perform professional activities [8]. The professional standard specifies generalized labor functions. It contains data on the employee's level of education, knowledge and skills for a specific type of activity. Each function includes a list of related labor actions. They are implemented when performing specific actions based on the necessary skills and knowledge. In accordance with the requirements of the professional standard [7], the employee's qualification assessment, i.e. determining whether the position meets the qualification requirements, should be conducted at least once every three years.

Currently, the national system of professional qualifications is being formed and changes are being made to the Labor Code. However, not all qualifications are formed and not all centers operate that are charged with their assessment procedure. By the decision of the National Council for Professional Qualifications under the President of the Russian Federation dated 23.06.2015, the Council for Professional Qualifications in the automotive industry performs an independent assessment of the qualification "Specialist in technical diagnostics and control over the technical condition of motor vehicles during periodic technical inspection".

On the website of the Federal State Budgetary Institution "VNII Truda", the Ministry of Labor of Russia presents a Register of professional qualifications councils authorized by the National Council for Professional Qualifications under the President of the Russian Federation [9]. At the same time, the Council for Professional Qualifications in the automotive industry was created on the basis of the non-profit partnership "Association of Russian Automakers". The Qualifications Assessment Centre (QAC) is subordinate to the Council for Professional Qualifications and conducts professional examinations. To date, for the specialty "Specialist in technical diagnostics and control over the technical condition of vehicles during periodic technical inspection", regional centers have not been formed. Therefore, the employer can evaluate the compliance of specialists with the requirements of the professional standard on its own or involve a specialized organization.

The employer can independently assess the employee's compliance with the qualification requirements within the framework of staff assessment or certification. Assessment is regulated by local regulations of the enterprise, and certification — by Federal acts and the Labor Code of the Russian Federation. The procedure for checking compliance with the professional standard is documented, and the employee participation is not required. In this case, a Commission is created by the order, which includes employees of the personnel, legal services, training departments, trade union representative (if available), and others. To determine the level of education and practical experience of the employee, the commission analyzes the employment record and copies of educational documents. Members of the commission determine the length of service for the desired profile, university and specialty of education. Based on the results of the audit, a free-form report is drawn up on whether or not the employee's education and experience meet the requirements of the professional standard.

According to the second option the qualification assessment is carried out using evaluation materials that are developed and approved in accordance with the requirements of the professional standard. The exam involves two stages: theoretical and practical. The employer can independently develop assessment materials or contact training centers where training and assessment of qualifications for this professional standard are conducted. Theoretical exam involves checking the knowledge of regulatory and legislative documents regulating labor functions, as well as the technological content of the activities of specialists in diagnosing and monitoring the condition of vehicles. For the exam, test questions are developed with the choice of an open answer, tasks to establish compliance, tasks to establish the sequence of execution. If employees do not pass the certification, they are offered training. You can take retraining and advanced training courses before certification on a voluntary basis. In case of failure, the applicant is given an opinion on his results with appropriate recommendations, the implementation of which will help in the future to successfully pass the professional exam.

Conclusion. The stated provisions on the formation of the certification system for transport enterprises' specialists ensure the improvement of road safety. At the same time, the assessment of qualifications allows an employee who does not have a professional education, but has work experience, to adapt more confidently to the labor market, allows planning a professional career. This increases the competitiveness of citizens in the labor market, and gives the employer the opportunity to adjust measures aimed at ensuring safety of conditions and compliance with labor protection requirements.

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Information about the authors:

Egelskaya, Elena V., Associate Professor, Department of Operation of Transport Systems and Logistics, Don State Technical University (1, Gagarin sq., Rostov-on-Don, 344000, RF), Cand. Sci., Associate Professor, ORCID: https://orcid.org/0000-0003-3864-9254, egelskaya72@mail.ru

Sorokina, Darya N., Senior Lecturer, Department of Operation of Transport Systems and Logistics, Don State Technical University (1, Gagarin sq., Rostov-on-Don, 344000, RF), Cand. Sci., ORCID: https://orcid.org/0000-0002-6691-0563, naukauni@mail.ru

Contribution of the authors:

E. V. Egelskaya — scientific supervision, formation of the main concept, goals and objectives of the research, correction of conclusions; D. N. Sorokina — preparation of the text, analysis of research results, revision of the text, formation of conclusions.

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Adaptive remote monitoring and control system for the operation of hazardous facilities based on a risk-based approach

A. V. Panfilov, O. A. Bakhteyev, V. V. Deryushev, A. A. Korotkiy

Don State Technical University (Rostov-on-Don, Russian Federation)

Introduction. When designing technically complex industrial facilities and transport infrastructure facilities, much attention is paid to the safety of operation and maintenance. Despite all the measures taken during the development of systems, there are cases of violation of the operating rules, as well as the maintenance of a hazardous facility of inadequate quality. Non-compliance with the requirements leads to malfunctions, accidents, and in some cases, to accidents. With the development of the Internet, it becomes possible to develop devices that allow you to control a large number of parameters of technically complex devices and transfer their parameters to a single database, for subsequent processing and decision making.

Problem Statement. The article discusses the methodology of adaptive remote monitoring and control of the operation of hazardous facilities based on a risk-based approach, which is a product of the Internet of things. This is a recommendation system for making a decision on the safety of hazardous facilities based on the assessment of risk indicators taking into account the functional and linguistic criteria of the actual technical condition.

Theoretical Part. A feature of the proposed methodology is an algorithm for developing a decision on the safety of an object in real time, which provides an integrated assessment of anthropomorphic and machine data in the cloud space of the Internet using neural networks and artificial intelligence technologies, followed.

Conclusion. The main result of using the recommendation system is the reduction in accidents during the operation of a dangerous object, due to the actual reliability of remote control, which is used in the development of decisions of a precautionary nature, with a decrease in the subjective nature of human thinking.

Keywords: security, remote monitoring, control, risk-based approach, risk assessment, risk prediction, advisory decision-making systems, the Internet of things.

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Introduction. The development of legislation in the field of industrial safety, taking into account the digitalization of the economy, involves remote control of the operation of hazardous facilities. The draft Federal law on amendments to the Federal law "On industrial safety" proposes to introduce state monitoring of industrial safety based on automated collection, recording, generalization, systematization and evaluation of information using remote monitoring of hazardous production facilities [1]. The implementation of the model of state regulation in the field of industrial safety is based on a risk-based approach [1-4]. Technical progress and modern legislation impose new requirements to the safety of objects based on a risk-based approach. There is still a high accident rate at hazardous facilities. Statistics show that it is 90% related to the human factor [5, 6]. One of the promising directions for improving safety is the introduction of methods for monitoring the operation of hazardous facilities to control their technical condition, as well as the work of personnel when performing scheduled maintenance [7-9].

The aim of the research is to develop a methodology for adaptive remote monitoring and control of the operation of hazardous facilities based on a risk-based approach, which is a product of the Internet of things.

To achieve this goal, the tasks listed below are solved.

1. Creation of a mathematical apparatus for processing information about the current state of hazardous facilities, which allows predicting and assessing the risks of emergency situations, taking into account functional and linguistic parameters.

2. Development of a methodology for creating an Internet of things product in which physical objects are hazardous facilities equipped with built-in technologies for interacting with the external environment via the Internet. The new solution must have the ability to re-engineer economic and social processes (including supervisory functions), partially eliminating the need to involve human consciousness.

3. Remote formation and updating of official and production instructions for specialists operating a hazardous facility.

4. Delivery of linguistic checklists to personal mobile devices of specialists for monitoring the technical condition of the facility.

5. Performing a daily functional check of the local security system of the controlled object and transmitting the received information to the server database.

6. Creating a color visualization of the recommendation system for making decisions on the accident risk parameters of the controlled object and the indications of the local security system.

Problem Statement. The risk-based approach in control and supervisory activities provides remote impact on the objects of control of supervisory functions based on the assessment of the risk of their accidents (incidents) and the consequences of such events. One of the most promising areas in this area is the introduction of information technologies. The new solutions obtained in this way are software products that work in real time. They collect information about the current state of hazardous facilities, which allows you to predict and assess the risks of emergency situations, and transmit information about the risk of an adverse event rather than about an event that has occurred. Based on such data, it is possible to react timely to the probable danger [10-13]. The proposed information technologies are a product of the Internet of things (IOT), in which physical objects ("things") are hazardous facilities equipped with built-in technologies for interacting with the external environment. This phenomenon is capable of reconstructing economic and social processes, removing human consciousness from certain specific functions, including supervisory ones.

Theoretical Part. The solution to the problem of safe operation of hazardous facilities in their remote monitoring is based on digital Internet technologies integrated with mobile applications. Such products are implemented in the form of a specialized digital platform based on hardware and software tools for searching, storing, processing, providing and distributing information between platform participants. In this case, participants are primarily engineering and technical workers and maintenance personnel of a hazardous facility, the management of the operating organization, and inspectors of control and supervisory bodies. The developed digital platform must adapt to the specific features of hazardous facilities. For example, one of such platform’s components on transport should be a block that monitors, controls and informs passengers, including monitoring their health and compliance with anti-terrorist security measures.

This IT product is based on an algorithm for combinatorial interaction of elements of a recommendation system and a decision support system using functional and linguistic criteria for diagnostics of a complex security state. At the same time, the algorithm and criteria that determine the current state of safety of an object change (adapt) depending on external conditions and the identified objective causes of accidents and incidents at other hazardous facilities. This necessitates the use of artificial neural networks and machine learning algorithms to build an intelligent system that provides a transition (convolution) from an unstructured multidimensional fuzzy space of indicators that characterize the current state of object safety to a single indicator (integral indicator) that characterizes the risk of an accident (emergency situation).

Fixing the risk indicator is not in itself proof of compliance with or violation of security requirements, but indicates the possibility of such a violation and may be the basis for conducting an unscheduled inspection or other forms of control, up to the complete closure of the facility.

Decision support is relevant for complex multi-level systems (construction, transport, mechanisms, etc.). Information on assessing the state of equipment and the risk of accidents in such systems is poorly structured or not structured at all. This involves the use of large arrays of incoming data and multi-criteria schemes, complex, multi-level hierarchical event trees, and (or) nonlinear decision functions. This takes into account information received from: — sensors (functional criteria),

— service personnel and experts (linguistic criteria) [14-16].

The developed adaptive system for monitoring safety of operation of hazardous facilities based on information technologies and a risk-based approach can be used for monitoring safety in various areas, namely:

— in cranes, elevators, cable cars, escalators, lifts;

— in gas equipment [17];

— on transport — air, road, river, sea, railway;

— in industrial installations and aggregates [18].

The system under consideration and the digital platform implementing it are current innovative solutions that increase the level of industrial safety. The novelty of the proposed approach consists primarily in the introduction of devices for monitoring and controlling safety of facility operation based on a logical and linguistic model for assessing the risk of an accident or other adverse event.

Research Results. The decision on risk assessment in the operation of hazardous facilities is made based on a unique algorithm. It is a combinatorial transformation of linguistic criteria for diagnostics of the facility's security status (received from the company's specialists) and functional indicator parameters of the local security system (from the devices that the facility is equipped with). To increase the efficiency of the facilities' equipment with local security devices and to get information from them, the sensors are combined into blocks. The number of blocks and their functional purpose depends on the type of the facility and monitoring goals. For example, a vehicle safety monitoring and control device includes four main blocks that define:

— driver's status

— technical condition of the vehicle

— location, speed of movement of the vehicle, road condition and environment, compliance with traffic regulations,

— condition of passengers (cargo).

The data received from specialists and devices form a finite set of indicators (criteria). Linguistic criteria formed from human data are divided into criteria with a measurable base variable (numeric) and with an immeasurable base variable (ordinal), depending on the nature of the base variable (base set). Functional criteria generated from the data of the devices are always numeric. These linguistic and functional criteria generally form an unstructured or poorly structured fuzzy set of indicators (criteria for evaluating the object's security status). In this case the values of criteria on elements of a finite set of a hazardous facility form a matrix of estimates

$$X = \left\| x_{ij} \right\|_{n,m},$$

where $x_{ij} = k_j(a_i)$ is an assessment of the technical condition of the facility a_i on the k_j scale; n is the number of the facilities in the set $A = \{a_1, a_2, \ldots, a_n\}$; m is the number of linguistic and functional criteria (evaluation scales) in the set $K = \{k_1, k_2, \ldots, k_m\}$, which forms a criterion space, within which facilities are displayed as a set of points [19].

It should be noted that for ordinal linguistic criteria with immeasurable base variables, physical scales may not exist at all. In this case, when formalizing such criteria, some basic term sets $T = \{T_i\}$ consisting of several terms are used [20]. An example of an ordinal linguistic criterion is a criterion with the terms GOOD, MATCHES, INSUFFICIENT, or BAD.

If the initial criteria space Re^m contains linguistic variables (including ordinal ones), then the integral indicator formed as a result of transformations that characterizes the risk of an accident (abnormal situation), in general, will also be an ordinal linguistic variable L.

The possibility assignment equation is necessary to establish a quantitative correspondence between the feature of an object (the ordinal linguistic variable L) and the property S, which the object may possess to a vague (indefinite) degree [20]. In this case, the property S represents the state of the object that determines the safety of its operation. It is important to emphasize that the uncertainty of the presence of this property in an object is not probabilistic, but possible. The possibility assignment equations for linguistic variables are based on the following principle.

The general statement P that defines the linguistic variable L is written as: L is G, where L — m-ary variable in the criterion space Re^m (m is the number of criteria that form the criterion space Re^m and are included in the linguistic variable L corresponding to the general concept of accident risk during object operation); G is a fuzzy relation in the base space $X = X_1 \ldots X_m$ between subsets S_i ($i = 1, \ldots, m$) describing individual properties that determine the object's safety state. Then the distribution of possibilities associated with the m-ary variable L will be determined by the equation:

$$\Pi_L = G,$$

where Π_L is the distribution of possibilities associated with the linguistic variable L.

This equation is a formalized expression of a complex linguistic concept — "the risk of an accident (emergency) during the operation of an object". Thus, a fundamental problem of fuzzy set theory arises — the problem of assigning numerical estimates to subjective properties. The main method for solving this problem is to construct membership functions of object belonging to a fuzzy set [19]. When introducing membership functions to the risk assessment model, we use the axiomatic structure proposed in [20] for the fundamental measurement of fuzziness. According to the definitions and theorems introduced there, the resulting values of the membership function are bounded from below by the number assigned to the a_{min} object or its equivalence class $[a_{min}]$, and from above by the value assigned to the a_{max} object or its equivalence class $[a_{max}]$. Here a_{max} is an object whose membership function indicates that it definitely has the property S; a_{min} is an object that definitely does not have the property S.

The evaluated property S splits the region A with the physical media $X(A)$ into three subdomains I_0, I_1, and F. Two "regions of indifference" I_0 and I_1 are formed by objects in the equivalence classes $[a_{min}]$ and $[a_{max}]$, respectively. The membership function for the" fuzzy area" F is usually constructed by formally specifying the security properties of specific objects.

Then in the system under consideration, for the ordinal linguistic variable ACCIDENT RISK, it is proposed to use three basic elementary terms corresponding to the subdomains I_0, I_1 and F, and two additional terms that are visualized as a color scale of indicators (table 1). The color of the hazard indication does not require decoding, it is intuitive to the manager, the personnel operating the facility, and is available to the controlling authorities. The object's belonging to one of the three main terms entered (fuzzy sets) is determined by the values of the so-called risk indicators.

Table 1

Determining whether an object belongs to one of the main fuzzy sets based on the values of risk indicators

Terms of the linguistic variable for assessing the risk of an accident at the facility	**Risk indicators**	
Acceptable risk level — operation of the facility is allowed as normal	Green	$u \leq u_{min}$ $a_i \geq s\ [a_{max}]$
Increased risk level — operation of the facility is allowed under increased control	Yellow	$u_{max} < u < u_{min}$ $[a_{max}] > s\ a_i > s\ [a_{min}]$
Critical risk level — operation is prohibited (as an exception, it is possible to perform single operations under strict control)	Red	$u > u_{min}$ $a_i \leq s\ [a_{min}]$
Risk level is not deftermined due to a system failure (malfunction)	Black	u — not determined
The facility is not operated	White	

As risk indicators, it is proposed to use the values of the universal variable which is entered when setting elementary terms in accordance with the requirements listed below [19].

1. Each term is described by a fuzzy subset of the set of values of the universal variable u from the interval [0,1].

2. The assembly of all elements of the term set covers completely the set of values of the base variable *X(A)* and the corresponding interval [0, 1] of the universal variable u.

3. Membership functions of elementary terms are constructed in the interval scale using *(L-R)* approximation or other methods [21, 22].

Taking into account these requirements, the membership functions of term sets describing the property of object operation safety are defined by the function

$$\mu D = 1 - u^{\gamma}.$$

If the risk indicator $u = 0$, then there is no risk and the operation of the object is absolutely safe. If the risk indicator $u = 1$, then the risk is critical and the operation of the object should be stopped.

The degree indicator γ determines the weak order on the $a_i a_j$ interval in the region A and determines the nature of the change in the membership function as the risk indicator increases. For $\gamma > 1$, the same deviations of the risk indicator lead to a greater increase in the membership function μ_D in the area close to zero than in the area close to one. In this case, if the risk indicator is low, its deviations do not significantly change the membership function of the object belonging to the safe area. If the value of the risk indicator is high, then its deviation changes this function much more.

So, the key points of defining the membership function are:

— conversion of the basic variables *X(A)* to the universal variable **u** defined on the interval [0, 1];

— determination of the values of the risk indicator u_{max} and u_{min}, which determine whether the object belongs to one of the three defined in table 1 main terms.

The stated functions of the logical-linguistic model of accident risk assessment in the operation of hazardous facilities are proposed to be implemented on the basis of a specialized digital platform developed with the use of neural network technologies.

In this system, the linguistic diagnostics of the technical condition of the object must use the knowledge, skills and abilities of a person, because it is almost impossible to cover all the parameters that characterize safety of operation of dangerous technical objects with instrument control methods. In addition, in real time it allows you to take into account constantly incoming information about the causes of accidents at similar facilities and changes in regulatory documentation.

Linguistic diagnostics of technical condition of the object in combination with instrument diagnostics create a synergistic effect. It manifests itself in a significant increase in the accuracy of diagnostics of the condition and assessment of risk of an emergency at the facility by reducing the degree of uncertainty. This is due to the mutual influence of all diagnostic parameters on each other in the process of machine learning using neural networks [23].

At the machine learning stage, the specialist makes adjustments to the algorithm for assessing risk of a possible accident and to the generated checklists based on visual prompts in the mobile app. This allows the system to learn how to automatically correct checklist templates by entering new diagnostic parameters. The block of forming linguistic criteria and corresponding checklists is based on the technologies of recommendation systems.

Of course, the structure of data collection in natural language is limited. The main requirement here is the clarity of the operator's answers to questions in the checklists. At the same time the proposed approach allows us to quantify typical non numeric responses: "a little bit", "a little", "recently", "long ago".

For example, the list of checklist questions that reflect the requirements of Federal Standards and Regulations on Industrial Safety (by type of equipment) depends on the type of the controlled facilities and the specific production situation. Common checklists include questions about the service life of the equipment, the latest industrial safety examination of the object and the last maintenance, the availability of insurance, the manufacturer of the work, etc. Special questions on the checklist for specific equipment, for example, relate to the assessment of the wearing of the flange surface and the rolling of the wheel; the presence of cracks on the drums, in the welds and the base metal; the level of wear of the drum stream along the profile, etc.

When training an artificial neural network, at this stage, responses are recognized using Natural Language Processing (NLP) technology and multicluster categorization of their content. In this case, a set of corresponding linguistic criteria is formed in the criteria space Re^m. In the end, machine learning allows the system to predict the time when the limit values of existing diagnostic parameters will occur. To do this, an approximation curve is constructed using a special algorithm, the training of which is corrected for each subsequent diagnostic operation.

Thus, the software for machine learning and adaptation of the security monitoring system uses modern algorithms based on neural networks that allow implementing the proposed approach taking into account operating modes, real weather conditions and non-standard situations [24-27].

For example, Fig. 1 schematically shows the interaction of participants, software and hardware parts of the digital platform of the proposed remote monitoring system for object security, which is based on the technical proposals of the patent [28].

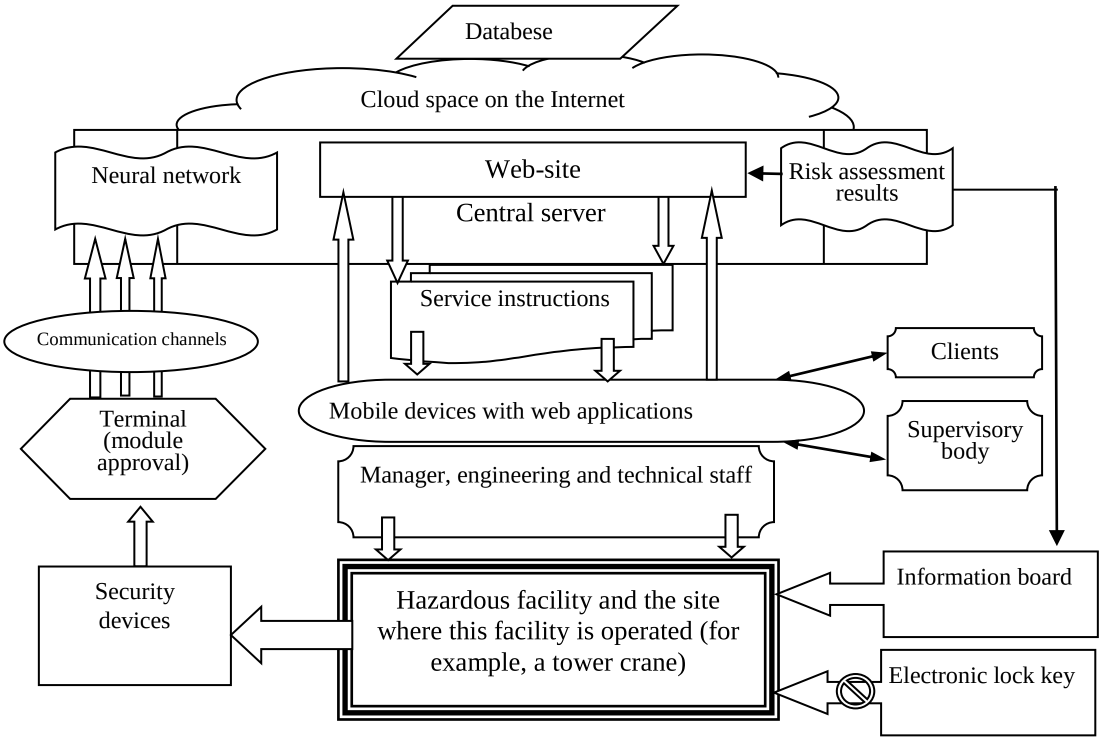
Databese
Cloud space on the Internet
Neural network
Web-site
Central server
Risk assessment results
Service instructions
Communication channels
Clients
Mobile devices with web applications
Supervisory body
Terminal (module approval)
Manager, engineering and technical staff
Security devices
Hazardous facility and the site where this facility is operated (for example, a tower crane)
Information board
Electronic lock key

Fig. 1. Block diagram of the digital platform

The database of the digital platform is uploaded to the Internet cloud space. It is accessed via a web site hosted on a central server. An unlimited number of registered users (with personal passwords and usernames) work with the system. Data is provided according to the degree of administration and level of confidentiality. Log in to the database is from individual mobile devices (computers, tablets, mobile phones, etc.) of managers, engineers, service personnel, customers, and representatives of the Supervisory authorities.

The central server uses neural networks to process information and requests from monitoring devices and personal mobile devices [29].

When creating and updating the database, the content of relevant legislative acts is taken into account. It is possible to create a selection of keywords from these texts, which are used to create checklists, and then production and job descriptions. These documents prescribe actions to assess the condition of the object, the safety of which is confirmed by the formation of linguistic indicators of the technical condition of the object. Instructions are delivered via the web application to individual mobile devices of registered users.

The information received by the server is processed using neural networks according to the risk assessment algorithm (described above and based on the theory of fuzzy sets by L.A. Zade). The user's mobile device receives the result of the calculation — the value of the risk indicator expressed in color (a color scale with three main and two additional colors is used).

Conclusion. The proposed system is the first fully combined digital solution built using technologies of recommendation systems (formation of linguistic safety criteria) and decision support systems (assessment of risk indicators for the operation of hazardous technical facilities). The features of this system:

— real-time integration of human and machine data,

— accounting for all available information,

— risk assessment and assistance to the operator in making decisions using several algorithms based on neural networks of the so-called artificial intelligence and Internet of things technologies.

Implementation of the system on the basis of the considered digital platform allows you to get the following advantages:

— to process information about the current state of hazardous facilities;

— to predict and assess the risks of emergency situations, taking into account functional and linguistic parameters;

— to remotely communicate to specialists service and production instructions updated to reflect changes in the legal framework;

— to send checklists to specialists' personal mobile devices for monitoring the technical condition of the object;

— to perform daily functional check of the local security system of the controlled object using checklists and transmit the received information to the server database;

— to recommend specialists to make decisions on safe operation based on color indicators;

— to record the received information in the database in accordance with the object identification and its location on the electronic map;

— to create an Internet of things product in which physical objects are dangerous objects equipped with built-in technologies for interacting with the external environment via the Internet.

Thus, the solution allows you to unify and systematize the requirements of the supervisory authorities for construction equipment, operation of machines, technological equipment and make recommendations based on objective data taken at the site.

The developed methodology is applicable for monitoring objects in remote and hard-to-reach regions.

The recommendation system is designed to reduce accidents when operating a hazardous facility. The result is achieved due to the actual reliability of remote control, since the role of subjective human thinking is limited in the development of preventive solutions.

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Information about the authors:

Panfilov, Aleksey V., Associate Professor, Department of Operation of Transport Systems and Logistics, Don State Technical University (1, Gagarin sq., Rostov-on-Don, 344000, RF), Cand. Sci., Associate Professor, ORCID: https://orcid.org/0000-0001-7211-1824, panfilov@ikcmysl.ru

Bakhteev, Oleg A., Assistant, Department of Operation of Transport Systems and Logistics, Don State Technical University (1, Gagarin sq., Rostov-on-Don, 344000, RF), ORCID: https://orcid.org/0000-0002-9631-7592, omp-rostov@list.ru

Deryushev, Viktor V., Professor, Department of Operation of Transport Systems and Logistics, Don State Technical University (1, Gagarin sq., Rostov-on-Don, 344000, RF), Dr. Sci., Professor, ORCID: https://orcid.org/0000-0003-1812-2834, deryushevv@mail.ru

Korotkiy, Anatoliy A., Professor, Department of Operation of Transport Systems and Logistics, Don State Technical University (1, Gagarin sq., Rostov-on-Don, 344000, RF), Dr. Sci., Professor, ORCID: https://orcid.org/0000-0001-9446-4911, korot@novoch.ru

Contribution of the authors:

A. V. Panfilov — assessment of the studied issue and the relevance of the research, participation in shaping the original concept, making the results of the study. O. A. Bakhteyev — participation in the design of block-diagram digital platform. V. V. Deryushev — development of the study methodology. A. A. Korotkiy — synthesis of research results, formulation of conclusions.

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Development of parametric criteria for assessing aircraft damage in a collision with birds

U. V. Esipov, E. A. Bochkova, A. Yu. Medvedev

Don State Technical University (Rostov-on-Don, Russian Federation)

Introduction. Taking into account the relevance of aviation incidents that occur as a result of strikes (collisions) with birds entering the flight zone of an aircraft (AV) and a posteriori analysis of these events, the article considers and tests parametric models and criteria for the implementation of accidents.

Problem Statement. Based on the well-known fuzzy parametric model "load p – carrying capacity σ", the problem of finding a possible (fuzzy) measure of damage to the aircraft and (or) the pilot in a collision with birds with varying mass and speed of the bird, as well as the area and duration of contact on impact is posed. The results of its solution are aimed at justifying the ornithological safety of flights by developing proactive actions to scare away and avoid areas of bird congestion both during takeoff and landing, and on the route of the vessel.

Theoretical Part. To describe and evaluate the following events (outcomes): 1) damage; 2) destruction; 3) fall of the aircraft, the well-known mechanical criterion of exceeding the load over the load-bearing capacity was applied. At the same time, the parameters of the load p and the carrying capacity σ were described as fuzzy values, which allowed us to find the values of the probability measure (as a subjective probability) of the implementation of outcomes in conditions of even insufficient statistics. The load parameter is represented as amplitude pressure pulse during impact and the collision of birds with an aircraft as a function of calculating the variation of the mass of birds, speed of mutual rapprochement of the bird and the ship, the duration of the impact and the area of contact of the bird with the vessel: $p=mv/(\Delta t\cdot\zeta)$ (scientific results 1). Based on the data obtained on the values of cores and fuzzy intervals of load capacity, as well as data on the values of cores and fuzzy intervals of the pressure amplitude in the impact, a possible measure of each of the accident outcomes was calculated (scientific result 2).

Conclusion. When a bird strikes with a mass of at least 1 kg and at a mutual speed equal to or greater than 50 m/s, the destruction of the fuselage will occur with a probability measure of 1.0, and when the pilot is exposed to the fuselage fragments, it may hurt him and the ship may fall. With the help of the obtained scientific results, a unified and reliable insurance basis for the ornithological flight risk is achievable.

Keywords: demage, collision, accident, safety of flights, aircraft.

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Introduction. Taking into account the relevance and public response of aviation accidents [1, 2], which often occur as a result of strikes (collisions) with birds (bird strikes), in the aircraft operating zone [3], a posteriori analysis of these events [2, 4, 5], as well as taking into account the formation of research on ornithological safety [5, 6], the article considers and tests the criteria for the outcome of accidents based on the parametric model "load — weakening — load-bearing capacity" [7-9]. Most often, bird strikes occur at low altitudes during takeoff and landing in the daytime. In Russia alone, there are about 7,000 cases a year. The speed of flight of birds is quite high for having not enough time to react in time to an approaching airliner at low altitudes. It is known that the flight speed of quails reaches 40 km/h, gulls — 60 km/h, starlings — 80 km/h, crows — 90 km/h, ducks — 120 km/h, Golden eagles — 130 km/h, swifts — 160 km/h. The risk of a bird strike depending on the bird's altitude is [1]: if the altitude is up to 100 m — 45.8 %, up to 101-

400 m — 28 %, 401-1000 m — 12.7 %, 1001-2000 m — 7.5 %, 2001-5000 m — 5.2 %, over 5000 m — 0.8 %. According to Rostransnadzor statistics, until 2008, on average in Russia there were 1.2-1.5 bird strikes of aircraft with birds for every 100 thousand flight hours, and starting from 2018, this figure is already equal to 3 (for every 100 thousand flight hours). During 2008-2018, the following situation in the field of ornithological danger was observed [1]: 2008 — 93 bird strikes with an aircraft; 2009 — 85 bird strikes; 2010 — 54 bird strikes; 2011 — 43 bird strikes; 2012 — 32 bird strikes; 2013 — 43 bird strikes; 2014 — 69 bird strikes; 2015 — 53 bird strikes; 2016 — 72 bird strikes; 2017 — 45 bird strikes; 2018 — 55 bird strikes. Statistical analysis revealed 3 main types of bird strikes with parts of the aircraft: with the engine — 43 %, with the fuselage — 27 %, bents and deformation of the fuselage — 30 %.

Since 2001, the Russian Federation has developed deterministic models and programs for calculating [3-5] damage to the ship and its parts. However, well-known models for calculating the risk and probability of accidents do not allow explicitly taking into account such characteristics of the situation in the "bird — air environment — aircraft" system as: the mass and speed of the bird, the area and duration of contact during impact.

Problem Statement. Based on the well-known fuzzy parametric model "load p — load-bearing capacity σ" [7,9], the problem of finding a possible (fuzzy) measure of damage to the aircraft and (or) the pilot in a bird strike with varying mass and speed of the bird, as well as the area and duration of contact on impact is posed. The results of its solution are aimed at justifying the ornithological safety of flights by developing proactive actions to scare away and avoid areas of bird congestion both during takeoff and landing, and on the route of the aircraft.

Theoretical Part. The parametric model "impact (load) — shield attenuation — load-bearing capacity (susceptibility)" is used as the basis for quantitative assessment of the accident [7, 8]. Based on the analysis of accidents that occur when birds and aircraft collide, it is possible to identify the most likely events such as damage, destruction, or fall of an aircraft. To describe and evaluate these events, the well-known mechanical criterion for exceeding the load p over the load-bearing carrying capacity σ [9.10] is applied. Moreover, in the first approximation, the load and load-bearing capacity are considered as fuzzy values [8], which allows us to find the values of the probability measure (as a subjective probability) of the outcome in conditions of even insufficient statistics [7].

Using the condition that the force pulse of a frontal impact is equal to the instantaneous value of the amount of mutual movement in the system "a bird with mass m — an aircraft with speed v", the load parameter is represented as the amplitude of the pressure pulse when a bird strikes and collides with an aircraft [8]

$$p = F/\zeta = mv/(\Delta t\cdot\zeta), \qquad (1)$$

where m — is the mass of the birds; v — closing speed of birds and aircraft; Δt — duration of impact; ζ — the area of contact of birds with the aircraft, F — force of the strike.

In fracture mechanics, the load-bearing capacity is most often assumed to be the stress corresponding to an irrevocable change in the shape of the structure, the beginning of flow or the formation of cracks [10]. In this work, the load-bearing capacity of the ship's fuselage was established as follows. According to the International Civil Aviation Organization, ornithological flight safety is based on the establishment of requirements for the load-bearing capacity of cockpit windows in the form of limit levels of the amount of movement on impact. In particular, the fuselage of an airplane or helicopter must withstand a bird strike of 0.9 kg at a speed of 50 m/s and 1.15 kg at a speed of 45 m/s [5, p.71], which is consistent with the expression (1) for the following values: $\Delta t = 0.01$ s and $\zeta = 10^{-1}$ m^2. This corresponds to the range of values of the mechanical stress of the beginning of destruction of the fuselage material 40-50 kPa.

Under the assumption of fuzzy parameters p and σ, a possible measure of the implementation of a parametric criterion describing damage is found from the expression [8]:

$$\pi_1 = Pos\,(p \geq \sigma_1),$$

where *Pos* (•) — *Possibility* operator[7, 9].

In the first approximation, assuming a linear approximation of the fuzzy parameters p and σ_1 (in the least informative variant of obtaining them), the following dependencies are used to calculate the probability measure [7, 9]:

$$\pi^L_i = 1 - \overline{zb}, \qquad (2)$$

where $\overline{zb}$ — reduced parametric safety margin":

$$\overline{zb} = (\bar{\sigma} - \bar{p})/(\Delta_r+\Delta_s). \qquad (3)$$

Here $\bar{\sigma}$ and $\bar{p}$ — are the "cores" of the fuzzy parameters of load-bearing capacity σ_1 and load p respectively; Δ_σ and Δ_p — are the "blurring intervals" of the fuzzy parameters of load-bearing capacity σ_1 and load p (рис. 1).

To generalize parametric modeling and quantify any event, a dimensionless representation of vertex outcomes is used based on a trapezoidal approximation of the load membership functions $\mu(s = p)$ and the load-bearing capacity $\mu(r = \sigma_1$ or $r = \sigma_2$ or $r = \sigma_3)$ (see Fig. 1) [9]. This means that the load-bearing capacity of the body, fuselage, and the aircraft itself is expressed as a"ruler" of the values of critical stresses σ_1, σ_2, σ_3 and their membership functions: $\mu(r = \sigma_1$ or $r = \sigma_2$ or $r = \sigma_3)$.

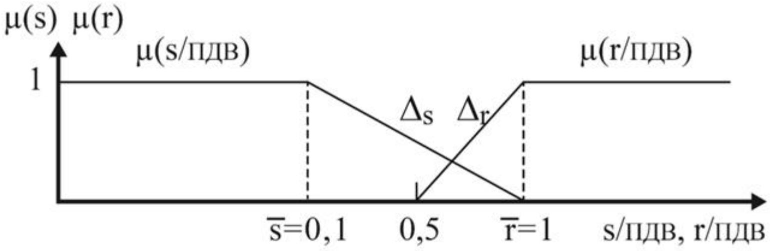

Fig. 1. Fuzzy dimensionless unified parametric model of vertex outcomes based on a trapezoidal approximation of the load membership functions $\mu(s = p)$ and the load-bearing capacity: $\mu(r = \sigma_1$ or $r = \sigma_2$ or $r = \sigma_3)$

We include the following in the vertex outcomes of the impact of birds on an aircraft:

1. VO1 — damage (deformation) of the body and (or) elements of the aircraft, parametric criterion:

$$p \geq \sigma_1,$$

where p is the area of possible change in the amplitude of the pressure pulse at impact, Pa; σ_1 is the minimum mechanical stress, Pa, or, in general, the area of change in the load-bearing capacity, which determines the damage (deformation) that affects the flight of the aircraft.

2. VO2 — destruction of the fuselage, leading to depressurization and (or) loss of the pilot's ability to continue flying, parametric criterion:

$$p \geq \sigma_2,$$

where σ_2 is the mechanical stress of the beginning of destruction of the fuselage material, which affects the pilot as a mechanical factor (formation of fragments of destruction and the impact of fragments on the pilot) and a chemical factor (depressurization).

3. VO3 — fall of the aircraft and (or) death of the pilot, parametric criterion:

$$p \geq \sigma_3,$$

where σ_3 — mechanical stress breakdown of the fuselage material, affecting the pilot, the aircraft's control system and leading to its fall.

For the assessment, we use a "three-level" representation of the membership functions in the form of an "assembly" of the aircraft's load-bearing capacity parameters, which describes the effect of increasing danger and the occurrence of vertex outcomes VO1, VO2 and VO3 with increasing loading, taking into account monotony. Based on the analysis of experimental and calculated data [1, 5, 8, 10], the following values of cores and blurring intervals of the load-bearing capacity parameters are obtained:

$$\sigma_1 = [1,\ 10]\ \text{кПа};\quad \overline{\sigma}_1 = 10\ \text{кПа};\ \Delta_{\sigma 1} = 5\ \text{кПа};$$
$$\sigma_2 = [40,\ 50]\ \text{кПа};\quad \overline{\sigma}_2 = 50\ \text{кПа};\ \Delta_{\sigma 2} = 10\ \text{кПа};\qquad (4)$$
$$\sigma_3 \geq 1000\ \text{кПа}\quad \overline{\sigma}_3 = 1000\ \text{кПа};\ \Delta_{\sigma 3} = 100\ \text{кПа}.$$

For these load-bearing capacity ranges, taking into account changes in the bird speed in the range of 40-60 m/s and the mass of 1-3 kg, as well as data on the duration and area of impact contact [2, 4, 5] in the ranges of 0.01–0.03 s and 0.05–0.1 m^{-2}, respectively, the following significant areas of change were selected and the amplitudes of the pressure pulse in the impact were calculated (Table 1).

Table 1

Calculated values of the amplitude of the pressure pulse of birds hitting the aircraft,
$p = p(m, v, \Delta t, \zeta)$, kPa

Bird weight m, kg	Impact duration Δt, s		
	0.01	0.02	0.03
	Contact area $\zeta \cdot 10^{-1}$, m^2		
	0.5–1.0	0.7–1.0	0.8–1.0
	Velocity v, m/s		
	40	50	60
	$p = p(m, v, \Delta t, \zeta)$, kPa		
1.0	40–80	25–35.6	20–25
3.0	120–240	35.6–108	60–75

Based on the data on the values of cores and fuzzy load-bearing capacity intervals, as well as calculated data on the values of cores and fuzzy load intervals in the form of the pressure amplitude at the impact, the calculation of the possible measure of the outcomes VO1, VO2 and VO3 was performed using formulas (3) and (4) (Table 2).

Table 2

Source data on parametric models of vertex outcomes and calculated values of possible measures for their implementation

Vertex outcome	Possible measures	Calculated pressure impulse at impact, kPa $[\ \overline{p}_i,\ \ \overline{p}_i + \Delta_{\overline{p}i}\ ]$	Lower limit of load-bearing capacity, kPa $[\ \overline{\sigma}_i - \Delta_i,\ \ \overline{\sigma}_i\ ]$
VO 1	$\pi_1 = 0.5$	20–25	15–30
VO 2	$\pi_{21} = 0.297$	25–35.6	40–50
	$\pi_{22} = 1.0$	40–80	
VO3	$\pi_{31} = 0.051$	35.6–108	100–1500
	$\pi_{32} = 0{,}173$	120–240	

As follows from Table 2, the deformation of the body with the possibility measure $\pi_1 = 0.5$ will occur when it collides with a bird weighing 1 kg or more. When the area increases and the contact duration decreases when the aluminum wall is hit, there is no destruction in this range of speed and mass.

Here is an example of calculating the possibility measure for the outcome VO2, taking into account the data in Table. 2.

$$\pi_{21} = 1 - (\ \overline{\sigma} - \ \overline{p}\ )/(\Delta_r + \Delta_s) = 1 - (\ 50 - 35{,}6\ )\ /\ (\ 10 + 10{,}6) = 0{,}297.$$

Taking into account the accepted boundary conditions, we find a possible measure:

π_{22} = 1 – (50 – 80) = 1,0.

Based on the data in Tables 1 and 2, the following conclusions can be drawn:

1. Destruction of the fuselage during the collision with a bird weighing equal to or more than 1 kg, at a speed equal to and more than 40 m/s, when the contact area is not more than 0.05 m^2 happens according to the possibility measure π_{21} = 0.3.

2. If the strike is stronger with the mass of birds over 1 kg and at a speed over 50 m/s the destruction of the fuselage happens according to the possibility measure π_{22} = 1.0. In addition, the effects of fuselage fragments at the pilot may cause air crash.

3. Fall of the aircraft and (or) death of the pilot will occur with the probability measure π31 = 0.051 when the body of the aircraft collides with a bird of mass equal to or more than 3 kg at a speed of 50 m/s and a contact area of 0.07 m^2 or less. When a bird strikes the body of the aircraft with a pressure pulse in the range of 120-240 kPa, the fall of the aircraft or the death of the pilot will occur with the probability measure π_{31} = 0.173.

Conclusion:

1. Based on the fuzzy parametric model "load p — load-bearing capacity σ", the problem of finding a possible (fuzzy) measure of damage to the aircraft is formulated and solved.

2. An analytical expression is proposed and tested of the load parameter in the form of the amplitude of the pressure impact on the ship as a function of the mass of birds, closing speed of the bird and the ship, as well as duration and contact area of the bird with the ship.

3. Taking into account the requirements of the International Civil Aviation Organization the load-bearing capacity of the cockpit windows was expressed as a fuzzy value of the mechanical stress of the beginning of the destruction of the material of the fuselage housing, the load-bearing capacity of the fuselage of the ship expressed as a range of values of critical stresses σ1, σ2, σ3 and their membership functions.

4. The authors have obtained possibility measures values as subjective probabilities for the lack of damage to the body, destruction of the fuselage and the aircraft falling in the range of 0. 051–1.0 in the collision with a bird weighing up to 3 kg and in the speed range of their closing speed up to 60 m/s.

5. When a bird strikes the body of an aluminum aircraft with a pressure pulse in the range of 120-240 kPa, the fall of the aircraft or the death of the pilot will occur with the probability measure of 0.173 and this approximately means the implementation of one of the five outcomes.

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Information about the authors:

Esipov, Yuriy V., Professor, Department of Life Safety and Environmental Protection, Don State Technical University (1, Gagarin sq., Rostov-on-Don, 344000, RF), Dr. Sci., Professor, ORCID: https://orcid.org/0000-0001-6018-5391, bulyur_rostov@mail.ru

Bochkova, Ekaterina A., Post-graduate student, Department of Life Safety and Environmental Protection, Don State Technical University (1, Gagarin sq., Rostov-on-Don, 344000, RF), ORCID:https://orcid.org/0000-0001-7989-2459, Bochkova.ekaterina2014@gmail.com

Medvedev, Aleksandr Yu., Master's degree student, Department of Life Safety and Environmental Protection, Don State Technical University (1, Gagarin sq., Rostov-on-Don, 344000, RF), ORCID: https://orcid.org/0000-0003-0758-9332, aleks.barsik@mail.ru

Contribution of the authors:

Yu. V. Esipov — scientific supervision, formulation of the research concept, obtaining and editing scientific results; E. A. Bochkova — literary analysis, preparation of scientific result 2, editing the text; A. Yu. Medvedev — collection and analysis of literary data, participation in the development of scientific results 1 and 2.

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On the substantiation of promising areas for improving road design safety

O. V. Denisov, L. A. Londareva

Don State Technical University (Rostov-on-Don, Russian Federation)

Introduction. The article considers the increasing role of highways in the economy of the modern state. A number of advantages of motor transport are listed and described: flexibility of delivery, speed and reliability of transportation, absence of unnecessary overloads of delivered materials, and economy.

Problem Statement. The authors substantiate the claims that the quality of roads significantly affects road safety, and the critical excess of the number of permissible shortcomings in their operation, deviations from standards and norms lead to the risk of losing the complex of operational qualities of road construction objects.

Theoretical Part. The paper analyzes the dynamics of road construction in our country in the past century. The features of road construction caused by the influence of a number of heterogeneous factors are determined. Examples of modern reconstruction of highways in metropolises are given, which allow determining the main requirements for a modern road and its main consumer properties.

Conclusion. Road construction will become more advanced if digital technologies are used — systems based on artificial intelligence, neural networks, etc. The technologies of the next decades, which will control the entire system "design-repair-production-control–transportation", will allow you to get high safety indicators in the field of road construction.

Keywords: roads, operation safety, logistics systems of vehicles, artificial intelligence, neural networks, generative design.

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Introduction. The circulatory system of the economy of any modern state is highways. They are designed to meet the needs of legal entities, the economic complex and individuals in transportation. This task cannot be fully implemented without an appropriate road network.

In logistics systems, vehicles have a number of advantages: flexibility of delivery, high enough speed, reliability, absence of overloads on the delivered materials, relative economy.

According to the technical terms, we can say that highways are a complex of engineering structures that include: earth foundation, road surface, capital construction objects, technical systems for the construction of the road network, special safety elements and structures, as well as buildings and structures of car services, road transport and road maintenance organizations. The vast territory of Russia with various geographical densities of settlements, economic objects and agricultural areas requires an optimal approach to designing a safe road network, taking into account the logistics flows of goods and services.

Theoretical Part. After analyzing the dynamics of road construction, we can conclude that since the beginning of road transport in our country (from about 1925) and until the last decade of the twentieth century, the size of the standard road network has increased by more than 65 times. In the post-war decade (from 1950 to 1960), the size of the standard road network built increased each year by about 9,000 km, and with the introduction of heavy road construction equipment (after 1960) by more than 20×10^3 km per year. The largest increase in the network of state roads (public roads) with paved surfaces was achieved during the last economic spurt of socialism (1966-1975) — an average of 26 thousand km per year. By the early 80's, the roads stretched for 800 thousand km. At the same time, historical statistics show that for various, mainly economic, reasons, since the mid-70s, the speed of construction of road facilities has been decreasing [1].

Highways in the European part of the Russian Federation diverge in the form of a multi-beam star, as it was in the days of horse-drawn transport more than a hundred years ago. Today, this network topology can be explained by weak horizontal economic links between cities and regions of our country.

The Russian automobile fleet is growing at a significant rate, which requires the development of the road network. The amount of vehicle shipment is 1.5 times higher than by rail, 5 times higher than by pipeline, and 8 times higher than by water.

The increase in the intensity of automobile traffic has led to significant wear and destruction of roads. As a result, the need for repair and restoration work has increased. The analysis of statistical materials has shown that roads in the country today do not meet the requirements of evenness, need strengthening repairs of the coating, have standard fencing structures, and are operated without visible or applied markings.

If you do not pay enough attention to repair and restoration work, road condition will become worse. This will result in reduced labor productivity, increased operating costs, machine wear (by 30%), and the number of accidents.

As of 2020, the state of roads in major metropolitan areas (with the exception of Moscow) is difficult. One of the problems of the Russian Federation, along with the lack of competence of individual managers in the field of construction and operation of highways, is the lack of necessary financial resources for current, major repairs and reconstruction of the street network. For this reason, the allocated limited financial resources are spent inefficiently [2].

Finally, there are positive examples of road reconstruction in the street network. In the early nineties, a complete reconstruction of the Bolshaya Sadovaya street in Rostov-on-Don was made. The reconstruction involved not only removing the top layer of pavement, but also removing the entire base structure to the paving stones laid at the beginning of the 20th century. At the same time, numerous utilities were replaced, entrances to buildings, work was performed on the roadway, and paving slabs were laid. After that, serious repairs were almost not carried out. However, high-quality reconstruction of the street allowed increasing the inter-repair cycle to almost a quarter of a century [3].

In the modern history of the Russian Federation, there are very few such examples in the reconstruction of highways in megacities. The main requirements for a modern highway, taking into account its category, are indicators of technical level and operational condition, namely the following properties:

— cost-effectiveness, which is the most relevant indicator due to the high cost of construction and operation, even when compared with the cost of similar roads in Europe;

— traffic speed, which determines the capacity of the road and is provided by the quality of the design of the route, artificial structures, roadbed and pavement;

— traffic safety, which involves the rational arrangement and maintenance of serviceable technical condition of the road and road structures, traffic regulation with the installation of road signs, various fences, systems for traffic order, which reduces the number of congestion and accidents;

— ease of use of the road due to improved driving and the ability to stop safely for various reasons. For example, in the United Kingdom, motorways provide a roadside in the form of a reduced lane with a road surface. Every 3 km there are free telephones with the road service's information desk. This experience can be used in our country;

— calculated load on the road is provided by the projected design of road pavement and engineering structures. Due to various reasons, including underestimation of design loads, ruts, longitudinal and transverse cracks appear on the road surface, which subsequently leads to the destruction of the road surface. In Canada, where frosts can tear not only concrete, asphalt, metal, but also be stronger than in central Russia, part of the roads (90%) is made of dirt with a crushed stone surface, on which you can move up to 100 km/h. Road sections are assigned to teams equipped with scrapers, rollers, and tipper trucks.

In Russia, measures to charge for the use of roads for heavy-payload vehicles using the Platon system solve economic problems of improving the quality of roads with less than optimal efficiency [4].

Problem Statement. In order to improve the quality of road construction and operation, it is necessary to implement a set of measures integrated into a system that provides, for example, the following parameters:

— $К_{д}$ — processing of legal and regulatory documentation for compliance with the best world analogues;

— $К_{р}$ — increasing the level of training for managers and specialists involved in the design of new construction, reconstruction, capital and current repairs of roads in localities and outside the urban road network;

— $К_{м}$ — increasing requirements for the quality of materials products and structures used in the road sector;

— $К_{т}$ — application of advanced methods and technologies in the road sector under various conditions of work.

These parameters are determined by the past historical and modern levels of development of road construction equipment and technology in the Russian Federation and in the world. The level of development of road construction equipment and technology does not always allow ensuring high quality and reliability of key parameters (for example, road surface) [5].

Exceeding the permissible norms in the construction of road surface may not be related to the total current level of development of techniques and technologies of road construction, but can lead to road traffic accident (RTA). Then an accident is a probabilistic event, where, for example, the cause may be a person or a technological failure.

The probability of an accident is determined by the probability of an event: in the first case — an anthropogenic error when driving a vehicle in difficult road conditions or physical inability to control the vehicle in difficult road conditions(simultaneously and/or sequentially) $\{P(A)\}$, in the second — $\{P(A)\}$ and the probability of technical and/or technological failures (man-made causes) - $\{P(T)\}$.

The risk of an accident can be determined by the condition of the main objects (person, car, road) that are "normal" or "not normal". "Normal" also does not exclude risks for a certain time of human activity, road or car operation. The risk of an accident is determined by the probability P of a negative situation and its consequences X:

$$R= \{P, X\}.$$

In this case, the scalar value — the mathematical expectation of consequences can be described as an indicator of the risk of an accident:

$$R= PX.$$

The normal operation of road transport network facilities is characterized by small (permanent) loads (microdamage) that affect people (this issue is addressed by labor protection) and the environment (environmental problems from internal combustion engine emissions). These loads may be small, but they are mandatory, with a probability close to one (P_{norm} ~1).

Emergency situations, such as road accidents, are characterized by much greater but short-term loads (significant damage X_i and consequences) on people and the environment ($X_{extr} >> X_{norm}$), but with less likely negative event ($P_{extr} << 1$; $P_{extr} << P_{norm}$).

The analysis allows us to conclude that the quality of roads significantly affects road safety, and a critical excess of the number of permissible comments on their operation, deviations from standards and norms leads to the risk of losing the complex of operational qualities of road construction objects [6].

In addition, it can be noted that on certain road sections there are places that are characterized by a high risk of road accidents. These include railway crossings, intersections with main oil and gas pipelines, overpasses, and bridges. These places are potentially dangerous, since the probability of accidents, especially in case of transportation of particularly dangerous goods, will be significantly higher than the probability of these events occurring on other road sections.

Let us analyze an example related to the quality and integrity of the N-th road surface. Let us assume that the N-th road surface has n = 10,000 elements (one meter each), which independently of each other for a certain period of time T could receive damage with parameters that do not correspond to GOST with a probability $q = 10^{-4}$. If at least one element is damaged, the road on a section of 10,000 elements becomes unsafe. What is the probability of road failure during T?

Let the event A_i = [for a period of time, the Ti element of the road is in good condition (not damaged)]. Then the event C = [the road is serviceable and not damaged during the time period T] can be represented in a simple way

$$C = A_1 A_2 \ldots A_n,$$

the probability of which

$$P\{C\} = P\{A_1\}\, P\{A_2\} \ldots P\{A_n\} = p^n,$$

where $p = P\{A_i\} = 1 - P\{A_i\text{прот}\} = 1 - q = 1 - 10^{-4} = 0{,}9999$. In this case, the probability of failure of the road along the entire section of 10,000 elements when it becomes unsafe,

$$P\{C_{\text{прот}}\} = 1 - P\{C\} = 1 - (1 - q)^n = 1 - (1 - 10^{-4})^{10000} = 1 - e^{-1} = 0{,}632.$$

You will not be able to move safely along the road of this quality (the reliability of its many elements). It is necessary to constantly replace the coating that has become unusable, carry out patching repairs and similar works [7].

Discussion and Conclusions. The main idea of today's promising directions in improving the safety of road design and construction is that the engineer does not design the road surface, but only sets the necessary parameters and conditions. The program calculates the specified parameters and offers a number of ready-made optimized solutions. As a result, you may get roads that look like natural objects.

Such technologies will become real after the appearance of promising powerful programs with algorithms based on artificial intelligence and powerful construction 3D printers.

We will divide the promising areas into the following types:

– topological optimization (saving non-load-bearing material);

– application of trabecular porous structures in the form of a small beam, rod, road fence post;

– use of artificial intelligence based on neural networks and other computer decisions after they are made by each individual and society as a whole [8].

The main application domain of these promising technologies is a significant reduction in the weight of the materials used while maintaining or increasing the strength of the road surface. The main obstacle to the introduction of promising technologies is not software, but production. It is very likely that everything will change soon. These technologies will appear in the next decade, possibly simultaneously with the widespread use of unmanned vehicles, which can also take over the functions of monitoring the integrity of the road surface. As part of the system "design–repair–production–control–transportation" with probability indicators $q = 10^{-9}–10^{-12}$, you can expect safety indicators that tend to one.

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Information about the authors:

Denisov, Oleg V., Associate Professor, Department of Life Safety and Environmental Protection, Don State Technical University (1, Gagarin sq., Rostov-on-Don, 344000, RF), Cand. Sci., Associate Professor, ORCID: https://orcid.org/0000-0002-2983-6587, ovd63 @ mail.ru

Londareva, Lyudmila A., Assistant, Department of Life Safety and Environmental Protection, Don State Technical University (1, Gagarin sq., Rostov-on-Don, 344000, RF), Assistant, ORCID: https://orcid.org/0000-0002-8048-0803, londareva.mila@yandex.ru

Contribution of the authors:

O. V. Denisov – problem statement, theoretical materials, consideration of the example related to the road surface quality and integrity, participation in the preparation of materials to discuss promising directions in improving road design safety, general editorship of the article. L. A. Londareva – preparation of the analysis of road construction dynamics, historical references, main requirements for a modern highway, taking into account its category, indicators of technical level and operational condition, work with bibliographic references, preparation of the article.

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Combined solution to problems of increasing the efficiency of engineering systems of power supply and waste management

V. I. Bespalov, O. S. Gurova, O. N. Paramonova

Don State Technical University (Rostov-on-Don, Russian Federation)

Introduction. In modern conditions of economic development of society, technological complexes are used to obtain thermal energy, which is then converted into other types of energy, depending on the purpose of the engineering power supply system. They mainly use various types of organic and hydrocarbon fuels as an energy source. At the same time, along with the increasing demand of mankind for energy, there is a significant increase in the formation and accumulation of production and consumption waste, among which the largest volume is accounted for solid municipal solid waste (MSW).

Problem Statement. The purpose of this study is to provide a possibility for solving the problems of increasing energy production and improving the environmental efficiency of the MSW management system by formulating a scientific hypothesis and scientific approaches based on the main provisions of the theory of dispersed systems and considering MSW as a set of dispersed systems that have a certain amount of energy, and therefore, calorific value. Based on this approach, it is necessary to improve technologies for recycling MSW in order to extract the maximum amount of various types of energy from them.

Theoretical Part. The proposed fundamentally new scientific approach, based on the energy classification of certain types of waste in MSW, as well as energy indexing of technologies for their utilization, allows us to improve the modern system for handling MSW, based on the conditions for extracting the maximum possible amount of different types of energy from waste and ensuring a minimum (within the established standards) negative impact of waste on the environment.

Conclusions. The scientific hypothesis proposed by the authors is based on the fact that MSW can be used as a fuel that has a certain, very significant energy reserve. The authors plan further scientific research related to the identification, formalization and proof of certain patterns described as assumptions, which in the future will allow generalizing the scientific approach proposed for MSW to almost all other types of waste, which for a number of reasons cannot be recycled and reused.

Keywords*:* engineering systems of power supply, municipal solid waste (MSW), calorific value, MSW handling systems, energy classification of MSW, energy indexing of MSW utilization technologies.

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Introduction. One of the fundamental foundations of the development of the world economy is energy, the main task of which is to produce and transfer to consumers various types of energy (mainly thermal, electric, mechanical) to ensure the intensive development of all spheres of life of the world community [1-3]. At the same time, the main technological element of energy is engineering systems of energy supply, which are technological complexes that provide, firstly, the extraction of energy from various types of fuel (solid, liquid, gas) with its subsequent conversion, or the conversion of one type of energy of natural phenomena, processes and factors into another type, and, secondly, the transportation of the produced energy to consumers. Thus, an engineering power supply system is a set of generating, converting and transmitting power plants that provide consumers with all the necessary types of energy for its use in production and life processes.

In the world practice and in Russia, such engineering systems of power supply include (table 1, fig. 1):

— technological complexes that use various types of organic and hydrocarbon fuels (peat, coal, oil, gas, etc.) as a source of energy — boilers, thermal power plants (TPP), state district power plants (SDPP), thermoelectric power station (TPS), [4];

— technological complexes that use nuclear fuel as an energy source (weakly enriched or unenriched natural uranium, a mixture of uranium with plutonium (Mixed-Oxide fuel)) in the form of fuel elements (fuel rods) — nuclear power plants (NPP) [5, 6];

— technological complexes that use wind flow as a source of energy — wind power plants (WPP);

— technological complexes that use solar radiation as an energy source — solar power plants (SPP);

— technological complexes that use the heat of the Earth's interior as an energy source — low energy stations (geothermal power station);

— technological complexes that use water flows as a source of energy — hydroelectric installations (HI), hydroelectric power plants (HPP), tidal power plants (TPS), wave power plants (WPS);

— technological complexes that use as a source of energy by-products (waste) of agricultural production, processing and food industry-biogas plants (BGP).

Table 1

Main energy sources and engineering power supply systems

Energy source	Type of energy source	Energy conversion technology	Type of engineering power supply system
Fuel	Coal, peat, oil, gas, waste	Incineration	Boilers, TPP, SDPP, TPS
	Nuclear fuel: ^{233}U, ^{235}U, ^{239}Pu	Nuclear decay	NPP
	Nuclear fusion	Nuclear fusion	Nuclear fusion plants
Natural processes and phenomena	Movement of air in the atmosphere	Wind	WPP
	Solar radiation	Photoelectric effect, heat-exchange	SPP
	Geothermal heat of the Earth	Underground geothermal heat exchange	GPS
	River and sea currents, waves, tides	Movement of the water environment	HI, HPP, TPS, WPS
	By-products and waste of plants and animals	Biological processes	BGP

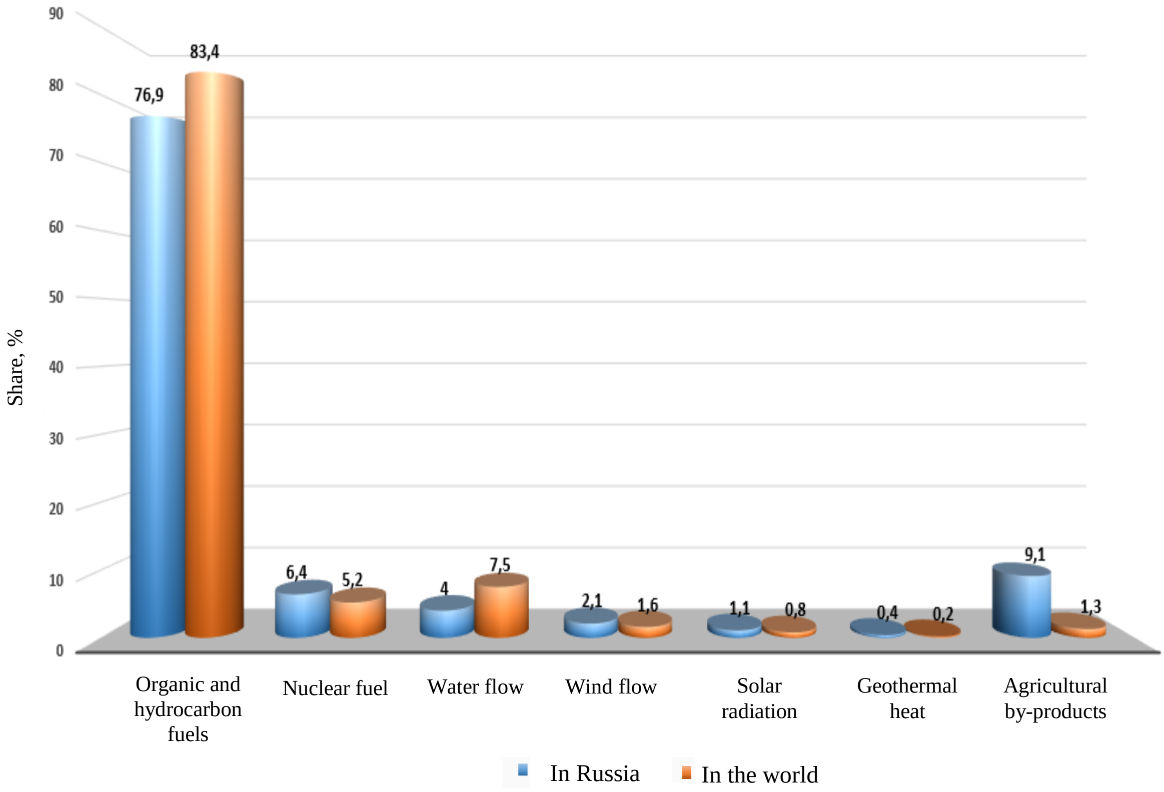

Fig. 1. Use of different types of energy sources in the world and in Russia

The analysis of the scale of application of these technological complexes in the world energy sector and in Russia allows us to conclude that the most widely used in modern conditions of economic development of society are technological complexes [4] that use various types of organic and hydrocarbon fuels as an energy source.

Technological structure of such power complexes, which are engineering systems of power supply, includes the following main units (Fig. 2):

- unit (I) for storage, preparation and supply of fuel to the combustion zone;
- unit (II) for fuel combustion and heat generation;
- unit (III) for converting heat energy to other types of heat (mechanical, electrical);
- unit (IV) for transportation of the produced types of energy (heat, electricity) to consumers;
- unit (V) for auxiliary technological processes that ensure reliable, uninterrupted, efficient, and safe operation of the entire energy complex.

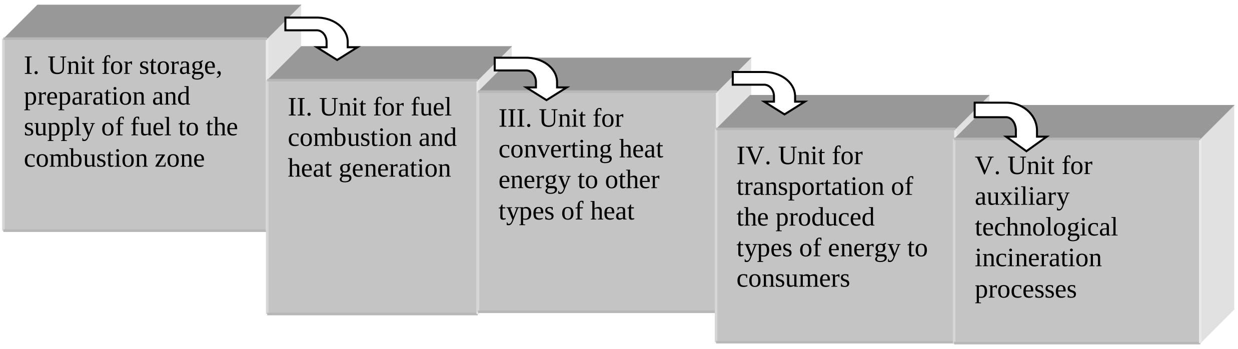
I. Unit for storage, preparation and supply of fuel to the combustion zone
II. Unit for fuel combustion and heat generation
III. Unit for converting heat energy to other types of heat
IV. Unit for transportation of the produced types of energy to consumers
V. Unit for auxiliary technological incineration processes

Fig. 2. Technological structure of power supply engineering systems

However, at present, in addition to thermal (combustion) technology, other technologies for obtaining energy from matter are known: exothermic chemical, photochemical, biological, and others. However, in the energy complexes described above, as the main technological process for extracting energy from fuel, a thermal process (the process of burning fuel) is used to obtain, first of all, thermal energy, which can then, depending on the purpose of a specific engineering power supply system, be converted into other types of energy (for example, mechanical and electrical) [7]. In this case, one of the most important characteristics of fuel in terms of the possibility of obtaining energy is its calorific value (J/kg, J/m^3, J/l), characterized by the amount of heat (J) released when the fuel is completely burned with a mass of 1 kg or a volume of 1 m^3 (1 l) (Fig. 3) [8, 9].

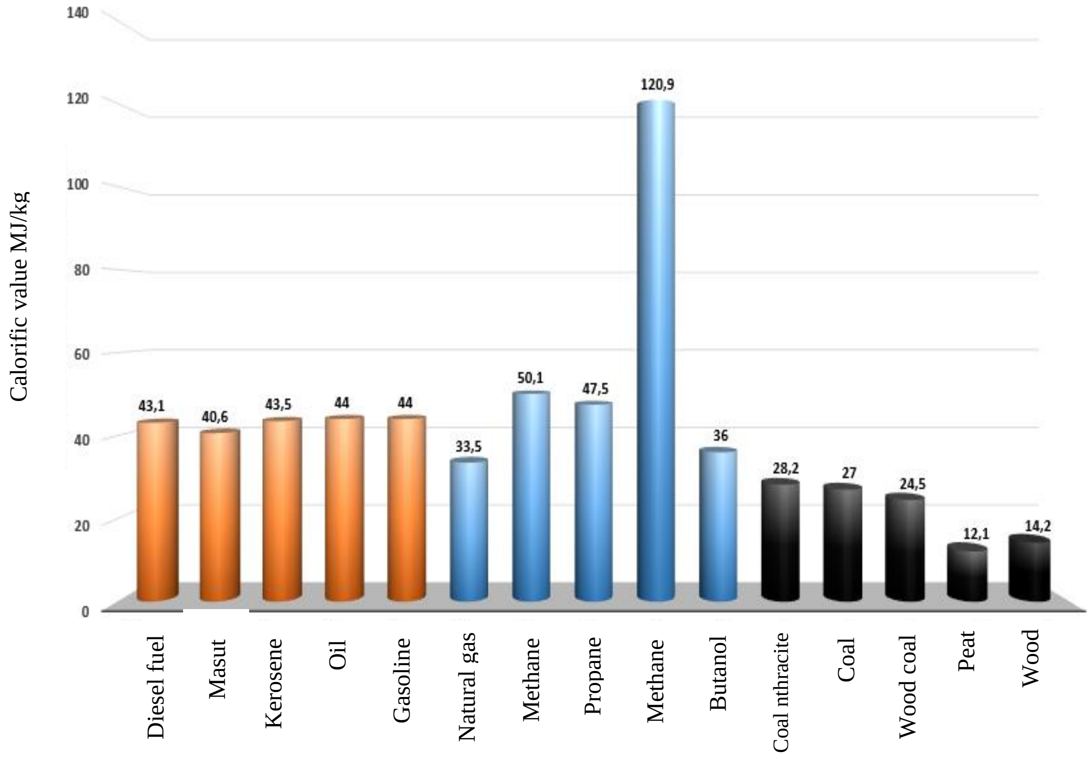

Fig. 3. Calorific value of various types of fuel

High values of calorific value of organic and hydrocarbon fuels explain the most widespread use in the energy sector of technological complexes that implement the process of burning this fuel [10].

Problem Statement. Despite the intensive development of world energy, in modern economic conditions, many countries are experiencing a constant shortage of production of various types of energy. In this regard, the problem of steady growth in energy production remains very relevant.

Along with the increasing demand of mankind for energy and the need for further development of energy in modern conditions, there is a significant increase in the formation and accumulation of production and consumption waste, among which the largest volume is accounted for solid municipal waste (MSW) [11]. The problem of handling MSW is directly related to the possibility of an environmental hazard at the international level and can lead to significant environmental pollution if it is not promptly removed and neutralized. At the same time, the organization of MSW management systems is becoming more complicated every year, due to the constant increase in the mass (volume) of waste generated, the transformation of its composition and properties, as well as the lack of economic resources in many countries necessary for effective processing of the bulk of MSW and recycling of its residue.

Theoretical Part. That is why in modern conditions in Russia and in many other countries, at the state level special attention is paid to significantly improving the efficiency of the MSW management system based on improving technologies for its collection, accumulation, transportation, sorting, processing and utilization [12, 13].

The structure of the MSW management system implemented in modern conditions by many countries is quite effective from the point of view of ensuring the environmental safety of territories, and involves the implementation of the following main stages (Fig. 4):

- separate collection and accumulation of MSW, both "internal" (inside premises, buildings, structures) and "external" (outside premises, buildings, structures);
- separate transportation of MSW to the places of processing and sorting;
- additional sorting of MSW by morphological characteristics, dividing the volume of MSW to be further processed and the remaining volume of MSW to be further disposed of;
- additional separate transportation of MSW to processing sites;
- processing of the main volume of MSW by type, depending on morphological characteristics;
- collection and accumulation of the residue of MSW;
- additional sorting of the MSW residue by type, depending on morphological characteristics;
- additional separate transportation of MSW residue to disposal sites by type, depending on morphological characteristics;
- disposal of the remaining MSW, based primarily on its incineration.

This structure of the MSW management system allows sending up to 90-95% of waste for recycling and reuse, and only 5-10% of waste is subject to further recycling [14]. However, on a global scale, even this 5-10% constitutes an incredibly huge amount of waste, expressed in its mass or volume.

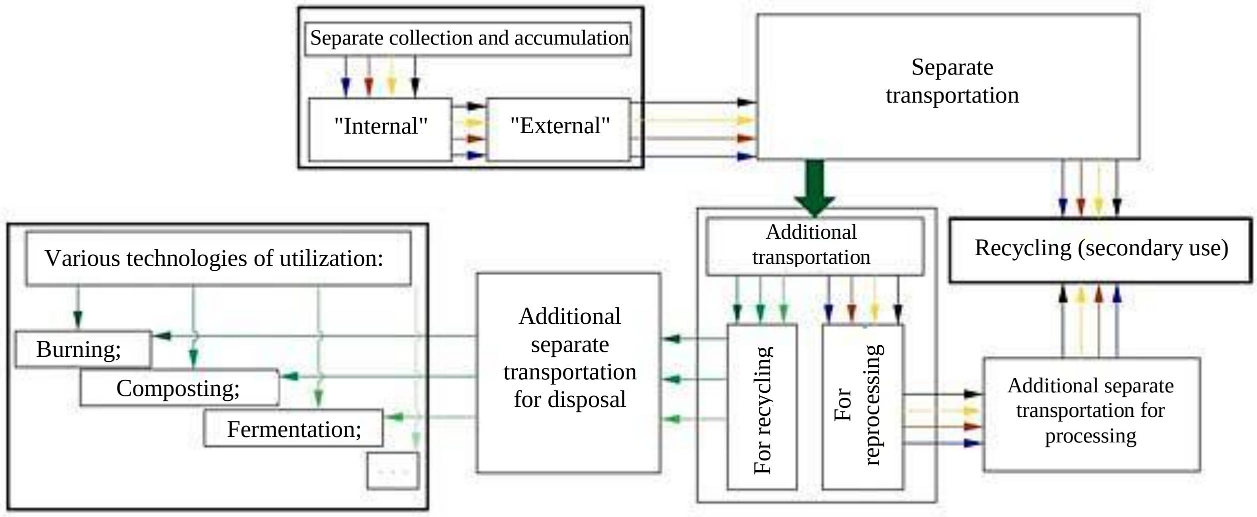
Separate collection and accumulation
"Internal"
"External"
Separate transportation
Additional transportation
Recycling (secondary use)
Various technologies of utilization:
Burning;
Composting;
Fermentation;
...
Additional separate transportation for disposal
For recycling
For reprocessing
Additional separate transportation for processing

Fig. 4. Structure of modern environmentally efficient MSW management systems

Considering the negative impact of the MSW management system on the environment, it can be concluded that the final stage — the disposal of the MSW residue makes the greatest contribution to the pollution of almost all the main components of the environment (atmosphere, water bodies and soil). In the world practice, various technologies for recycling MSW are used, based on the implementation of various physical, chemical, and biological processes: burial (storage in soil), incineration at different temperatures, composting (decomposition, biodegradation), fermentation, and others. In Fig. 4, waste, starting from the "additional sorting" stage, is separated by morphological features and sent for disposal by appropriate technologies (marked in green).

During a certain historical period, many countries used landfills as the main technology for MSW recycling. However, at present, most countries, having abandoned landfills, use incineration technology as the most effective from the environmental point of view.

The need to solve these two problems together led the authors to choose the directions for further research and formulate a scientific hypothesis, which is in:

- considering MSW as a set of dispersed systems that have a certain amount of energy, and, consequently, calorific value;

- considering each type of waste in MSW as a fuel characterized by a corresponding range of calorific values;

- classification of waste in MSW by groups according to the values of calorific value;

- classification of physical, chemical, biological and other waste management technologies in MSW, based on the capabilities of these technologies for extracting the maximum amount of various types of energy from waste;

- improving the structure of the modern MSW management system based on:

* inclusion of the stage associated with additional sorting of the MSW residue, but not by types, depending on morphological characteristics (as is currently accepted), but by groups, depending on the values of calorific value;

* choosing a recycling technology that will be optimal for the conditions for extracting the maximum amount of various types of energy from the waste of the selected group (in terms of calorific value).

Let us consider in more detail the main provisions of the proposed scientific hypothesis.

The proposed scientific hypothesis and a new scientific approach are based on the main provisions of physical and colloid chemistry, primarily on the theory of dispersed systems [15, 16], according to which any matter can be considered as a dispersed system. A characteristic feature of the dispersed system is the determining role of surface phenomena, since the interface of the phase components is quite large and represents a field of interphase interactions. According to this theory, MSW is a polydisperse system consisting of several solid dispersed phases (separate MSW fractions) and a gaseous dispersion medium (air layers between MSW fractions).

If MSW can be considered as a fuel, then its energy parameters can also be estimated by calorific value. And as some examples of world practice show, MSW may well serve as fuel, having sufficiently high values of calorific value (Table 2).

Table 2

Physical characteristics of certain types of waste in MSW

Examples of waste types	Moisture, %	Solidity, kg/m^3	Calorific value (specific lower heat of combustion), MJ/kg
Food waste of plant origin	60	80	3.43
Food waste of animal origin	75	170	6.21
Paper	25	130	11.49
Tree	5–20	150–160	14.46
Polyethylene film	8	75	23.37
PET bottles	8	27	
PVC bottles	8	54	
Textile	20	85	15.72
Skin	5	65	25.79
Rubber	0,75	160	

Since the calorific value (specific heat of combustion) of each type of waste considered as a fuel depends on the amount of combustible components and varies over a fairly wide range, it can be proposed to classify waste into groups (Table 3) in accordance with the calorific value.

Table 3

Energy classification of MSW groups by their calorific value

MSW group	Range of calorific value values, MJ/kg	Examples of waste types
1	less than 5	Food waste of plant origin
2	5–10	Food waste of animal origin
3	10–20	Paper, textiles, wood
4	more than 20	Leather, rubber, plastic film, PET and PVC bottles

Along with the energy classification of waste groups, the authors proposed energy indexing (classification) of waste disposal technologies in MSW, based on the capabilities of these technologies for extracting the maximum amount of various types of energy from waste. In this case, each technology can be assigned a corresponding index (Table 4).

Table 4

Energy indexation (classification) of waste disposal technologies in MSW by the amount of extracted energy

Index of recycling technology	Range of values of derived energy, MJ/kg	Type of recycling technology
1	less than 5	Biological
2	5–10	Chemical
3	10–20	Thermal low-temperature
4	more than 20	Thermal high temperature

Ultimately, the choice of the optimal recycling technology should be based on the conditions for extracting the maximum amount of various types of energy from the waste of the selected group (in terms of calorific value). The number of the waste group must correspond to the index of the waste disposal technology. Then the structure of the MSW management system (Fig. 4), taking into account the proposed scientific hypothesis and scientific provisions, can be transformed in relation to the appropriate waste disposal technologies (Fig. 5).

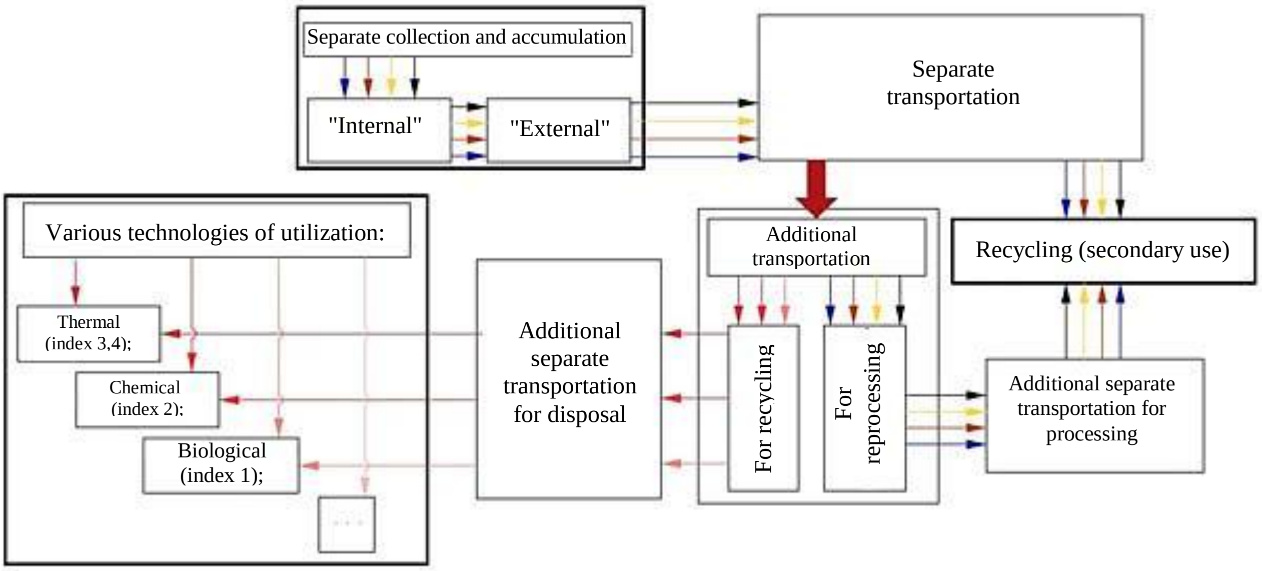
Separate collection and accumulation
"Internal"
"External"
Separate transportation
Various technologies of utilization:
Thermal (index 3,4);
Chemical (index 2);
Biological (index 1);
...
Additional separate transportation for disposal
Additional transportation
For recycling
For reprocessing
Recycling (secondary use)
Additional separate transportation for processing

Fig. 5. Structure of the proposed by the authors environmentally efficient and energy-efficient MSW management system

Thus, unlike the structure shown in Fig. 4, starting with the "additional sorting" waste is proposed to divide not by morphological characteristics, but by calorific values in accordance with the assigned group number of waste, and direct disposal technologies, with appropriate indexes (red color in Fig. 5).

Conclusion. Thus, the proposed scientific hypothesis is based on the fact that MSW can be used as a fuel that has a certain, very significant energy reserve. A fundamentally new scientific approach, proposed by the authors and based on the energy classification of both individual types of waste in MSW, and on the energy indexation of technologies for their utilization, allows us to improve the modern system for handling MSW, based on the conditions for extracting the maximum possible amount of different types of energy from waste and ensuring a minimum (within the established standards) negative impact of waste on the environment.

It should also be noted that further scientific research planned by the authors, related to the identification, formalization and proof of certain laws described as assumptions, will allow us in the future to generalize the scientific approach proposed for MSW to almost all other types of waste, which for a number of reasons cannot be recycled and reused.

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Information about the authors:

Bespalov, Vadim I., Head, Department of Environmental Engineering, Don State Technical University (1, Gagarin sq., Rostov-on-Don, 344000, RF), Dr. Sci., Professor, ORCID: https://orcid.org/0000-0003-2123-8141, izos-rgsu@mail.ru

Gurova, Oksana S., Professor, Department of Environmental Engineering, Don State Technical University (1, Gagarin sq., Rostov-on-Don, 344000, RF), Dr. Sc., Associate Professor, ORCID: https://orcid.org/0000-0002-7160-4288, okgurova@yandex.ru

Paramonova, Oksana N., Associate Professor, Department of Environmental Engineering, Don State Technical University (1, Gagarin sq., Rostov-on-Don, 344000, RF), Cand. Sci., Associate Professor, ORCID: https://orcid.org/0000-0002-7854-6703, paramonova_oh@mail.ru

Contribution of the authors:

V. I. Bespalov — scientific supervision and formation of the main concept, formation of the purpose and objectives of the research; O. S. Gurova — analysis of research results, revision of the text, correction of conclusions; O. N. Paramonova — preparation of the text, drawings, formation of conclusions.

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Using adaptive traffic lights for improvement of environmental situaiton at metropolis crossroads

G. A. Galchenko[1], M. V. Byrnysheva[2], D. S. Drozdov[3]

[1,2]Don State Technical University (Rostov-on-Don, Russian Federation)
[3]Southern Federal University (Rostov-on-Don, Russian Federation)

Introduction. Jams at crossroads lead to emissions in atmosphere of great volumes of pollutants. The problem of unloading of a transport artery can be decided partially by means of usage of an adaptive mode of switching of a light signal. The analysis of a transport situation should be executed previously by means of various means and program complexes.

Problem statement. The task of the given research is the analysis of a transport situation at crossroads of Rostov-on-Don on the basis of full-scale supervision and theoretical calculations, development of advisories on the enhancement of organisation of traffic.

Theoretical part. The main mathematical method on which basis the computer program is developed, the method of electrodynamic modelling is. The analysis of the given full-scale supervision, theoretical calculations and present-position sensors of availability of the car is carried out.

Conclusions. Full-scale supervision and mathematical calculations showed significant degree of intensity of traffic on the given crossroads. Installation of an adaptive light signal will promote improvement of a transport situation. For realisation of an adaptive mode of switching of a light signal it is offered to use TrafiCam - the sensor of availability of the car.

Keywords: methods, modelling, software product, vehicles, crossroads, ecology.

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Introduction. Transport problems in megacities, such as congestion at intersections, lead to a large amount of air-polluting emissions when the car engine is idling or running slowly. The problem of relieving pressure on roads is acute for departments of major cities. One of the solutions to this problem is the organization of traffic light regulation, taking into account the current transport situation. The decision to install an adaptive traffic light system should be based on the analysis of traffic situation at the intersection [1]. For the analysis, such approaches as field observations are widely used, which allow determining the structure and number of vehicles, software systems and technical tools.

Problem Statement. The initial objective of this study was to analyze traffic situation at intersections in Rostov-on-Don. Based on field observations and theoretical calculations, the recommendations for improving the organization of traffic are developed.

Theoretical Part. In this paper, we propose to use the developed software package "Material flow" [2-3] to analyze traffic situation at problematic intersections in order to determine the need to install an adaptive traffic light. The software package is developed using the method of electrodynamic modeling [4], which allows you to calculate the main characteristics of the transport situation (traffic intensity, tension and resistance) at a particular intersection.

As an example we used this program for evaluating and improving traffic management at the intersection of Voroshilovskiy ave. – Varfolomeeva street, Rostov-on-Don (Fig. 1). Traffic density is heavy at this intersection and congestions are frequent.

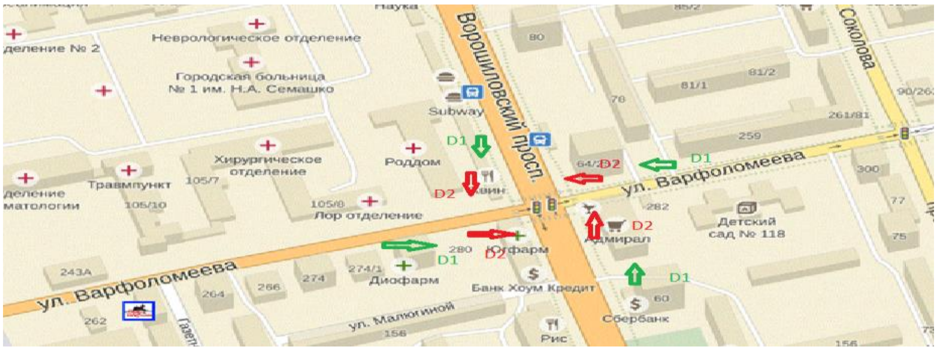


Fig. 1. Map of the intersection of Voroshilovskiy ave. – Varfolomeeva street, Rostov-on-Don

Field observations were made. The traffic congestion at the intersection was analyzed on different days of the week: during morning and evening peak traffic congestions (tables 1-3).

Table 1

Diagram of the number of passenger cars

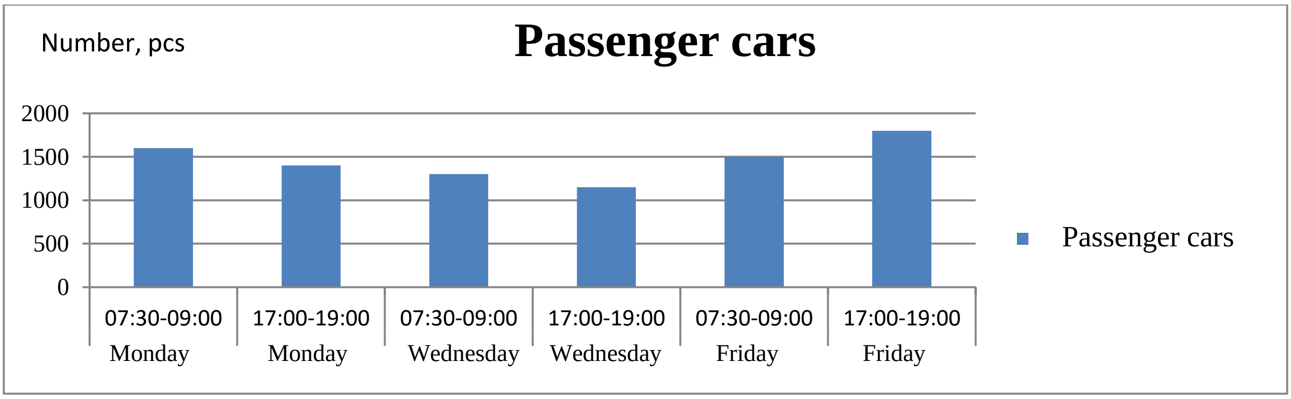


Table 2

Diagram of the number of trucks

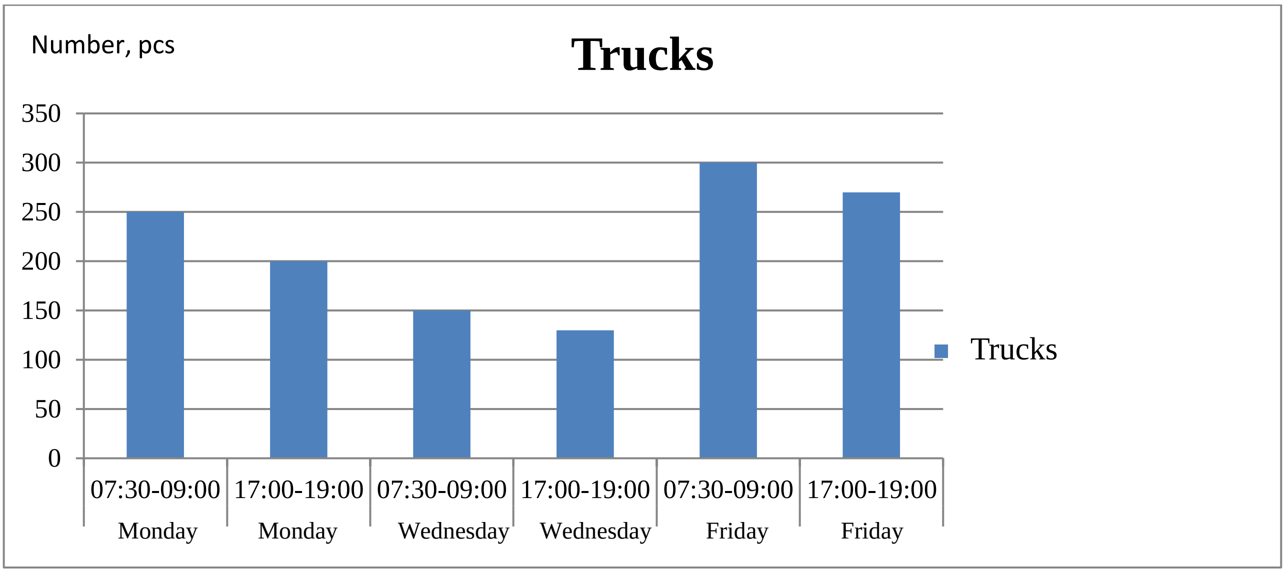
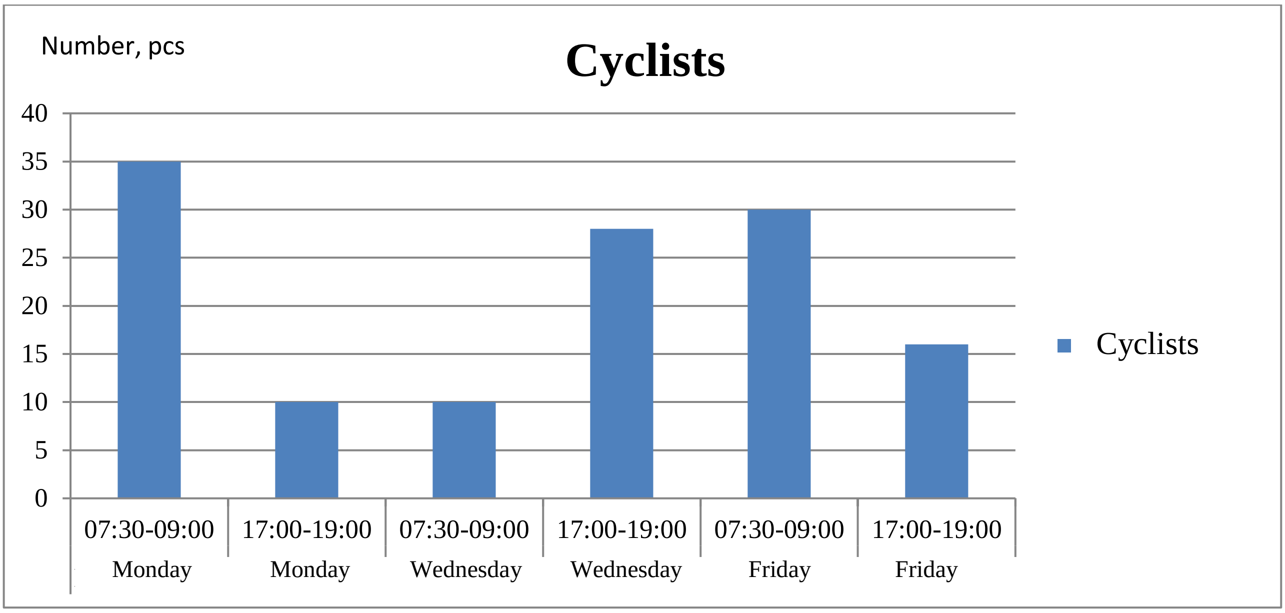


Table 3

Diagram of the number of cyclists



To calculate the main transport characteristics of the intersection Voroshilovskuy ave. – Varfolomeeva street, Rostov-on-Don, the method of electrodynamic modeling was used [5-7].

Calculations of the influence of vehicle speed on traffic intensity (I) were made (Fig.2) and resistance to movement (R) (Fig.3-4) at different values of the number of vehicles at the intersection and different values of grip of wheel (ψ) - different weather conditions.

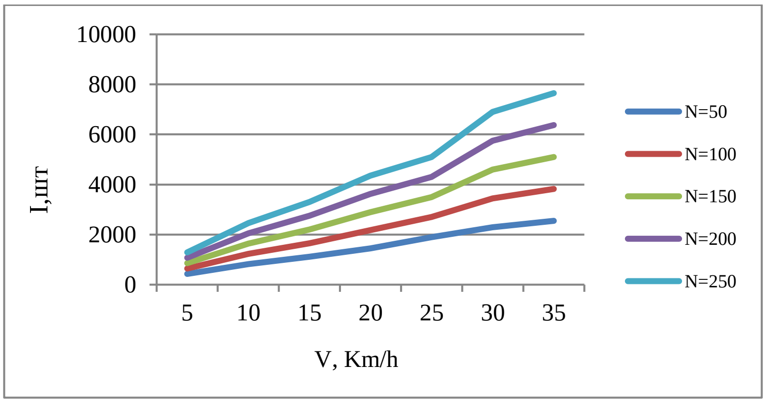


Fig. 2. Influence of vehicle speed on traffic intensity for different values of the number of vehicles (N) at the intersection

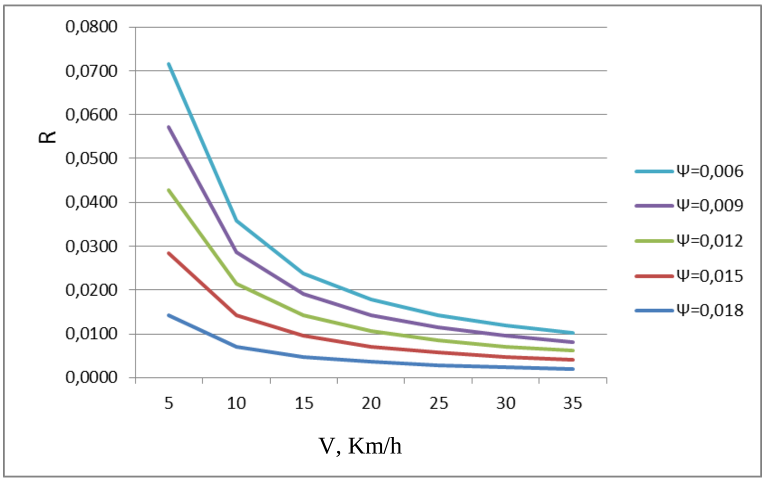


Fig. 3. Influence of vehicle speed on traffic resistance with a flow density of q = 100 and various weather conditions (ψ)

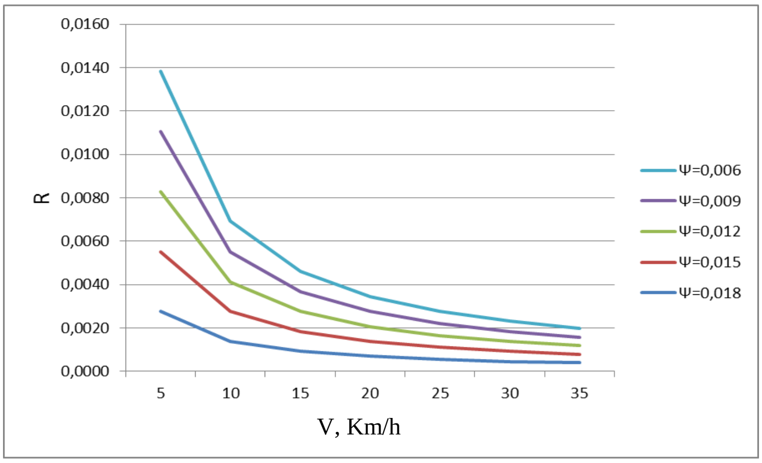


Fig. 4. Influence of vehicle speed on traffic resistance with flow density of q = 150 and various weather conditions (ψ)

The analysis of these dependencies allows us to conclude that there is heavy traffic at this intersection, the speed of the vehicle decreases with the increase in the number of cars, and the resistance to traffic increases, especially when weather conditions worsen. An adaptive traffic light can help improve traffic situation at this intersection. The adaptive traffic light is always accompanied by various types of sensors that are located before (D1) and after (D2) the intersection. The D1 sensor reads the identification number of the car approaching the intersection and enters it in the computer memory, while counting the number of cars approaching (N). As soon as N reaches a certain set maximum of Nmax, the green light turns on. A car that leaves the intersection is counted by the D2 sensor, which deletes the identification numbers of cars that passed through the intersection. The traffic light switches to a different phase and the traffic light cycle control program returns to the beginning of the cycle. This operation of the traffic light cycle is performed for both roads. The conventional layout of the sensors is shown in Fig. 5, and for the intersection in question, Figure 1 shows the arrows.

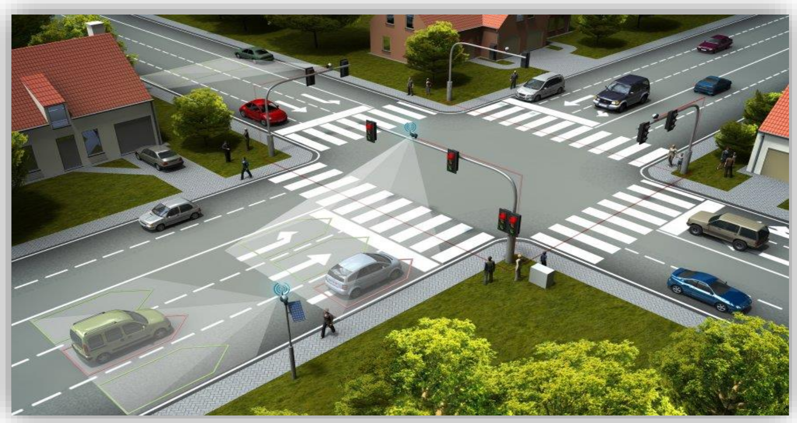


Fig. 5. Layout of sensors at a conditional intersection

There are a large number of sensors that can be used to implement this algorithm. The TrafiCam car presence sensor series is a combination of cameras with CMOS memory chips and video detectors. This series includes two products: the autonomous Traficam car presence sensor and the TrafiCam x-stream sensor with the function of collecting data from the video stream. Both TrafiCam and TrafiCam x-stream sensors are used to detect and monitor moving and stationary vehicles at controlled intersections. The user-friendly web interface allows users of TrafiCam x-stream sensors to manage their video sources ONLINE .

Fig. 6.a) TrafiCam Sensor

Fig. 6.b) Location of the sensor

Traffic violations are recorded using automatic video recording cameras. Today in Russia, the traffic police use the following types of cameras and radars:

Arena is a stationary complex. This system is designed to measure the speed of a vehicle and has software that allows you to recognize the registration number. It is usually installed at a height of no more than 8 meters and controls only one lane of traffic.

Arena 2 is a stationary complex. It is installed at a certain angle to the road and can control two lanes of traffic. The complex has sufficient memory in which information about violations is accumulated and transmitted to the appropriate post of the road patrol service.

Arena is a mobile complex, which is an easily moved device that can be placed on a tripod at a short distance from the road. Power is provided by a battery. Speed violations on this section of the highway are photographed and stored in the memory of the complex.

Speed camera "Berkut-Visa" - knowledge of the computer allows you to work with this device, using the capabilities of a video camera. The road situation is displayed on the device screen in real time. Information about violations, if the speed limit is exceeded on this section of the route, is stored in a file and in the computer memory.

TrafiCam car presence sensor series is a combination of cameras with CMOS memory chips and video detectors. This series includes two products: an autonomous car presence sensor that collects information from video stream data. Information about the presence of vehicles is transmitted via the corresponding outputs or via IP Protocol to the traffic light controller, and thus the duration of traffic light signals is dynamically adjusted. In this way, traffic flow is optimized by reducing waiting at intersections. The information is transmitted in full frame format, but can also be compressed in the appropriate formats. The interface of this series of sensors is convenient and allows you to work in ONLINE mode.

Conclusion. To simulate the optimal distribution of traffic light control modes, you can use the PTV VISTRO software product. This software allows you to work simultaneously with several intersections, optimizing and coordinating traffic. However, the cost of this product is very high, which limits its widespread use.

The proposed approach with the use of the developed software package "Material flow" allowed us to collect a fairly large database of problematic intersections in Rostov-on-Don [8], where adaptive traffic lights need to be installed. Of all these sensors, it is proposed to install TrafiCam - a car presence sensor, since this sensor counts cars and thus will relieve the road. If there is a traffic jam at an intersection that impedes traffic flow, the TrafiCam sensor can send information about the presence of cars to the system, which allows the system to change the switching pattern of traffic signals.

Adaptive traffic lights are widely used in many countries around the world. In Moscow, adaptive traffic lights are installed at more than 500 intersections. The above mentioned approach to traffic management on busy roads allows you to significantly increase the average speed of traffic and reduce tension of the entire transport system. For cities and regions of Russia, the use of an adaptive traffic light control approach will have a noticeable social effect [9-10], as it will reduce harmful emissions from cars and improve the overall environmental situation.

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Information about the authors:

Galchenko, Galina A., Senior Researcher, Department of Operation of Vehicles and Logistics, Don State Technical University (1, Gagarin sq., Rostov-on-Don, 344000, RF), candidate of physical and mathematical Sciences, Associate Professor, ORCID: https://orcid.org/0000-0001-5966-0423, ggalchenko@inbox.ru

Burnyasheva, Mariya V., Master's degree student, Department of Operation of Vehicles and Logistics, Don State Technical University (1, Gagarin sq., Rostov-on-Don, 344000, RF), ORCID: https://orcid.org/0000-0001-6707-6198, m.burnyasheva@yandex.ru

Drozdov, Dmitriy S., Student, Department of Computer Science and Computational Experiment, Southern Federal University (105, Bolshaya Sodovaya street, Rostov-on-Don, 344006, RF), ORCID: https://orcid.org/0000-0003-0381-1012, ds-drozdov@yandex.ru

Contribution of the authors:

G. A. Galchenko — scientific supervision, formation of the main concept, goals and objectives of the research, correction of conclusions. M. V. Burnyasheva — field observations, preparation of the text, formation of conclusions. D. S. Drozdov — development of a software package, calculations, analysis of research results, revision of the text.